Report

Task 4: Problem and Solution Identification and Prioritization for Hooffs Run, Alexandria, Virginia

Prepared for

City of Alexandria
Transportation and Engineering Services

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Executive Summary

The City of Alexandria, Virginia (the City), has experienced repeated and increasingly frequent flooding events attributable to old infrastructure, inconsistent design criteria, and perhaps climate change. The purpose of the stormwater capacity analysis project is to provide a program for analyzing storm sewer capacity issues, identifying problem areas, developing and prioritizing solutions, and providing support for public outreach and education. The project is being implemented in phases by watershed. The watersheds include Hooffs Run, Four Mile Run, Holmes Run, Cameron Run, Taylor Run, Strawberry Run, Potomac River, and Backlick Run.

This technical memorandum (TM) focuses on problem and solution identification (Task 4) for capacity issues in Hooffs Run. It summarizes the problem-identification steps, solution development, solution scoring, and alternatives analysis. This task has resulted in three watershed-wide alternatives aimed at resolving capacity-related problems in the Hooffs Run watershed. Additionally, this task has provided the City with a decision-making process for evaluating the benefits of potential stormwater management (SWM) projects.

The objectives of this phase of the study were to (1) identify and prioritize capacity problems based on modeling results from Task 2 of this project, and (2) develop and prioritize solutions to address those problems. In Hooffs Run, three different design criteria and one historical storm were examined during the Task 2 modeling analysis: (1) the City's existing intensity-duration-frequency (IDF) curve, (2) the updated curve using the full record of historical precipitation data available at the time of the analysis (1949 to 2008), (3) the curve projected for the year 2100 using various climate change scenarios, and (4) the June 25–27, 2006 storm event, estimated to be approximately a 20-year event based on volume and slightly less than a 10-year event based on peak intensity. The results of the Task 2 analyses showed that the existing IDF design hyetograph was the most conservative of the design storms (produced the greatest amount of stormwater runoff and flooding), and produced a similar amount of the system flooding to the results from the historic event. Consequently, this scenario was chosen to be used to complete the remainder of the project.

In the Task 2 modeling results, two areas in the Hooffs Run Watershed (Hooffs Culvert and Braddock & West Intersection) experience extreme capacity limitations with long backwater impacts. Because the backwater impacts limit the ability to identify and prioritize solutions for localized capacity limitations, major capacity projects were developed to improve backwater conditions prior to evaluating problems and solutions in the watershed. A conveyance and a storage option were evaluated for each of major capacity problem areas.

The conveyance solution was selected as the preferred major capacity solution for Hooffs Culvert. This solution consists of installing a 4,700 foot long, 6-foot by 10-foot box culvert to divert flow from Timber Branch down Russell Road into the western barrel of Hooffs Culvert near the intersection of Commonwealth Avenue and King Street. The estimated capital cost of the project is $13.6 million. The storage alternative evaluated consists of diverting flow from the Hooffs Run Culvert near E. Spring Street and sending it to a 13 MG storage facility under athletic fields at George Washington Middle School for an estimated $18.5 million in capital costs. The capital costs for the storage and conveyance projects are similar; however, due to the constructability and operations and maintenance implications of building a large storage facility, the storage alternative was not considered feasible.

A conveyance solution was also selected as the preferred major capacity solution for Braddock & West. This solution consists of diverted flow from upstream of the intersection along the railroad track right of way (ROW) through a 2,400 LF, 48-inch circular pipe. The estimated capital cost of the project is $1.4 million. The storage solution consists of constructing a 1.8 MG storage facility under the Braddock/West Metro station parking lot or under athletic fields at George Washington Middle School for a capital cost of approximately $2.8 million. The conveyance solution was selected due to lower capital cost and superior performance improving backwater conditions and downstream capacity limitations.

In addition to the major capacity projects, 9 baseline projects were identified in the Hooffs Run Watershed. Baseline projects were identified in locations where significant jumps in the hydraulic-grade line (HGL) were caused by short lengths of sudden diameter or slope change. The baseline improvement projects include replacement of approximately 1,910 LF of pipe, for an estimated capital cost of $0.83 million. Because many of the baseline projects include short lengths of pipe with extreme or sudden slope or diameter change, it is possible that the data contains errors; therefore all 9 projects may not be necessary.

The first objective of the study, identifying and prioritizing problems, was accomplished in two steps. The first step included evaluation of each stormwater junction in the drainage network using a scoring system to identify problems based on several criteria, including the severity of flooding, proximity to critical infrastructure and roadways, identification of problems by city staff and the public, and opportunity for overland relief. In the next step, high-scoring junctions (that is, higher priority problems) were grouped together to form high-priority problem areas. In total, 23 high-priority problem areas were identified in the Hooffs Run watershed.

The second objective involved developing and prioritizing solutions to address capacity limitations within the 23 high-priority problem areas. Several different strategies were examined to accomplish this objective, including improving conveyance by increasing hydraulic capacity, reducing capacity limitations by adding distributed storage to the system, and reducing stormwater inflows by implementing green infrastructure. Each of these strategies required a different modeling approach. Conveyance improvements were modeled by increasing pipe diameter in key locations within the problem area, storage was added as storage nodes based on a preliminary siting exercise, and green infrastructure was modeled as a reduction in impervious area at three different implementation levels: high, medium, and low. A single model run was set up for each strategy including solutions for all 23 high-priority problem areas and the results were compiled for the alternative and prioritization evaluation. Solutions were evaluated based on several criteria, including drainage improvement/flood reduction, environmental compliance, sustainability and social benefits, asset management and maintenance implications, constructability, and public acceptance. Planning-level capital costs were developed for each solution to facilitate a benefit cost analysis and prioritization process.

The results of the solution identification and prioritization analysis show the following:

- In terms of solution technology performance:
  - Green infrastructure generally has the greatest overall benefit as defined by the solution evaluation scoring system described in this report
  - Conveyance solutions and high implementation of green infrastructure generally provide the greatest flood reduction of the technologies/approaches analyzed in Hooffs Run
  - Combination of conveyance or storage projects and green infrastructure generally provides the greatest benefit and flood reduction
- In terms of costs:
  - Low level of green infrastructure implementation generally has the greatest cost/benefit score but did not usually meet minimum threshold for flood reduction
  - Conveyance and storage projects generally provide the most economical stormwater volume reduction in terms of dollars per gallon of flood reduction within a high-priority problem area
  - Combination of conveyance and green infrastructure generally provides the greatest overall benefit/cost score

Three watershed-wide alternatives were developed, including:

- Alternative 1: Most cost-effective solution for each problem area (lowest dollar-per-gallon of flood reduction)
- Alternative 2: Best benefit/cost ratio for each problem area (highest benefit/cost ratio)
- Alternative 3: Combination of best projects to address the worst problem areas to the extent practicable

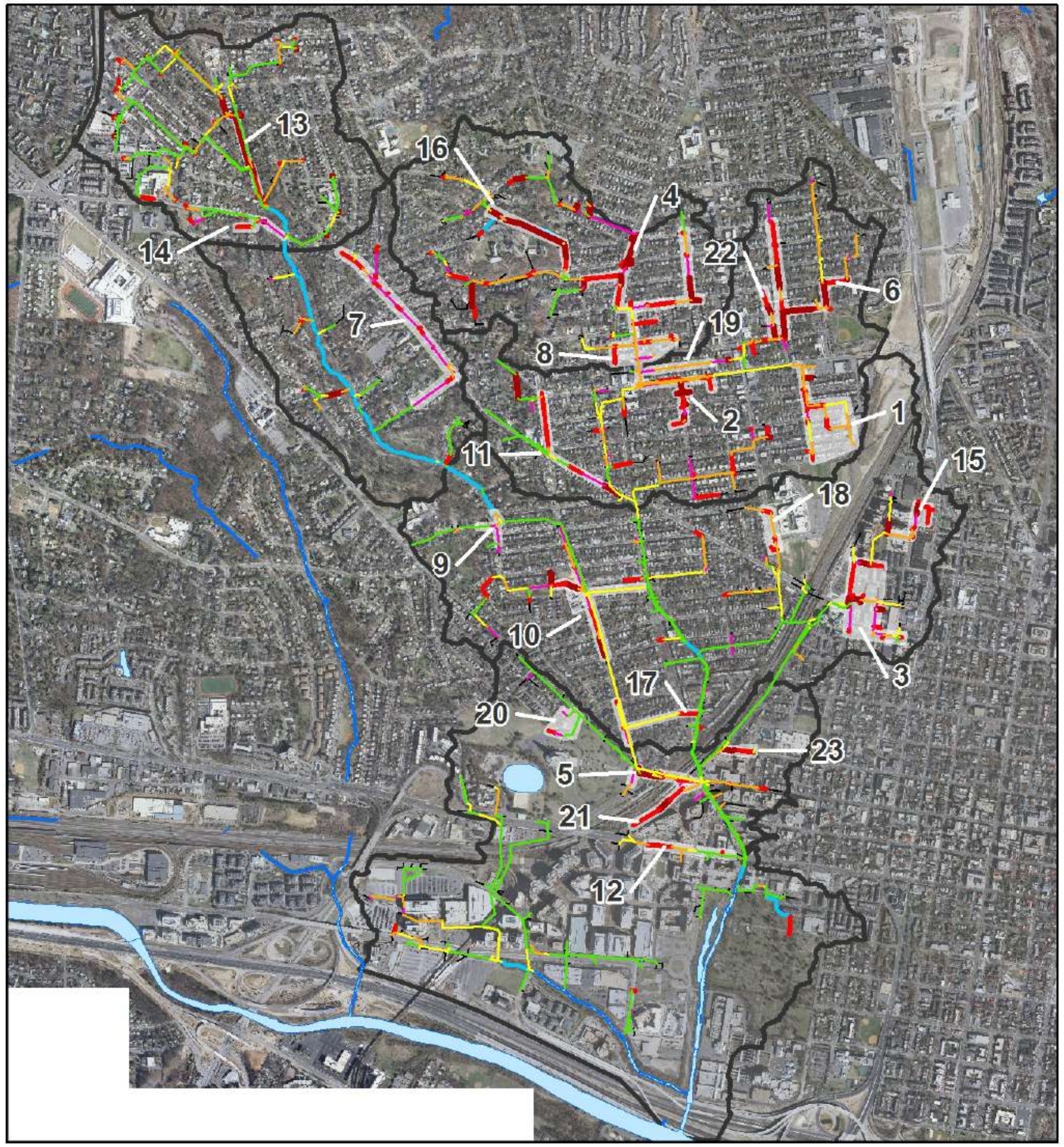
The results for each alternative reflect the objective upon which it was built to some degree. A summary of the results is provided in Table ES-1.

TABLE ES-1
Watershed-wide Alternatives Scoring and Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

	Alternative 1 Best Cost Efficiency	**Alternative 2 Best Benefit/Cost Ratio**	**Alternative 3 Highest-priority Problems**
Total Capital Cost ($ Millions)	$19.65	$18.10	$18.26
Total Benefit Score	811	984	978
Overall Benefit/Cost	41	54	54
Total Flood Reduction (Million Gallons)	6.90	6.82	7.36
Cost of Flood Reduction ($/Gallon)	$2.85	$2.65	$2.48

Though Alternative 1 was selected from the initial model runs as the solution with the lowest cost per gallon of flood reduction for each problem area, it is not the most cost-effective watershed-wide alternative. Alternative 3 focuses on providing relief in the 14 highest-priority problem areas that have more substantial flooding than problem areas 15 through 23, and when compared to Alternative 1, greater flood reduction was achieved in the model runs for a slightly lower cost in Alternative 3. Therefore, Alternative 3 is the most cost-effective watershed-wide alternative at $2.48 per gallon of flood reduction. Alternative 2 provides the highest total benefit score, though this scores is only slightly higher than Alterative 3, which offers slightly more flood reduction and focuses on the worst problem areas as defined by the problem identification scoring. Alternative 3 was selected as the most beneficial and cost effective watershed-wide alternative. Model results for the existing conditions model and the Alternative 3 watershed-wide alternative are presented in Figures ES-1 and ES-2.

FIGURE ES-1
Major Capacity Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



Legend

Model Results
Sufficient Capacity
Surcharged
Insufficient Freeboard

Volume (cu. ft.)
0.01 - 1,000
1,000 - 10,000
10,000 - 87,200
Not Analyzed (Private, disconnected, upstream of runoff input)

Subwatersheds
Water Bodies
Modeled Streams
City of Alexandria Streams

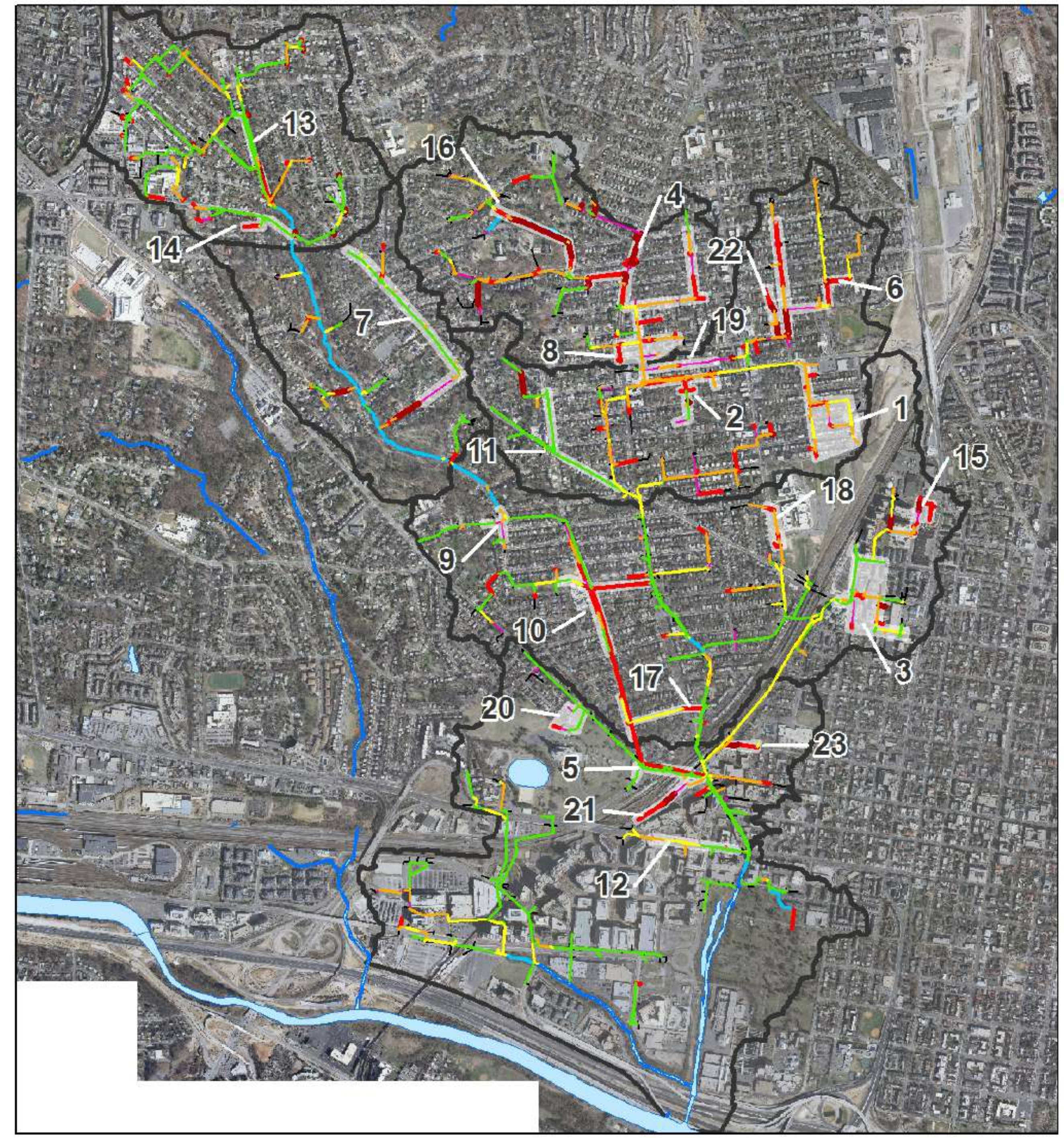
Major Conveyance Model Results and High Priority Problem Areas
Task 4 Problem and Solution Identification and Prioritization for Hooffs Run

0 750 1,500 3,000
Feet

N

CH2MHILL

FIGURE ES-2
Alternative 3: Highest-priority Problems Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



Legend

Model Results
Sufficient Capacity
Surcharged
Insufficient Freeboard

Flood Volume (cu. ft.)
0.01 - 1,000
1,000 - 10,000
10,000 - 43,000
Not Analyzed (Private, disconnected, upstream of runoff input)

Subwatersheds
Water Bodies
Modeled Streams
City of Alexandria Streams

Watershed Wide Alternative 3
Model Results and High Priority Problem Areas
Task 4 Problem and Solution Identification and Prioritization for Hooffs Run

0 700 1,400 2,800
Feet

N

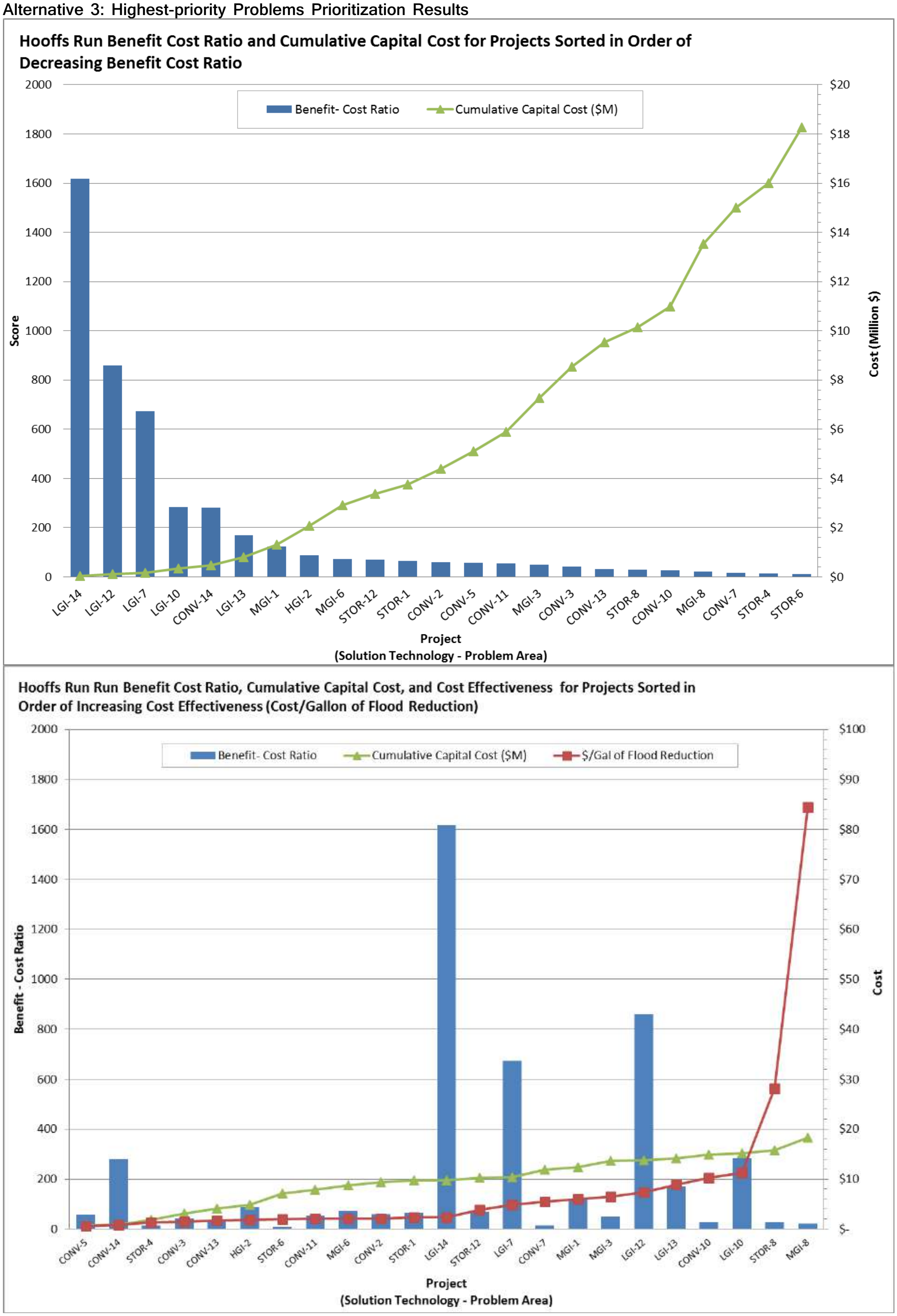
CH2MHILL

When developing a capital improvement plan, the benefit cost or cost efficiency ($/gallon of flood reduction) are typically used to guide the order in which projects are implemented. Prioritization results for Alternative 3 are presented in Figure ES-3. The top chart shows the total benefit score and the cumulative capital cost of the alternative. The solutions are provided in order of decreasing benefit cost ratio; solutions with the greatest benefit cost are presented on the left and solutions with the lowest benefit cost are presented on the right. The bottom chart shows the benefit/cost ratio for each solution in the watershed-wide alternative in order of increasing cost/gallon of flood reduction. Both charts show the cumulative capital cost plotted on the secondary axis. The solutions on both charts are named by the technology: conveyance (CONV), storage (STOR), low green infrastructure (LGI), medium GI (MGI), or high GI (HGI), and the problem area number.

It should be noted that the model does not include analysis on private property, but applies assumed runoff loads as inputs to the public conveyance system. The City chose not to include existing private or public stormwater management facilities upstream of the modeled collection system because of the limited available information on these facilities and a concern that the facilities may not be performing as designed. When the City moves forward into detailed evaluation and design of selected projects, it will be important to fully evaluate and account for the benefits of any existing stormwater management facilities.

The hydraulic modeling results and costs presented in this TM should be reviewed with the understanding that several assumptions were made to fill data gaps in the hydraulic model, and proposed solutions and costs were developed on a planning level.

FIGURE ES-3
Alternative 3: Highest-priority Problems Prioritization Results



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Acronyms and Abbreviations

bgs	below ground surface
cfs	cubic feet per second
City	City of Alexandria, Virginia
ft^2	square feet
ft^3	cubic feet
GI	green infrastructure
HGI	high green infrastructure
HGL	hydraulic grade line
hrs	hours
ID	identification
IDF	intensity-duration-frequency
LF	linear feet
LGI	low green infrastructure
MG	million gallons
MGI	medium green infrastructure
ROW	right-of-way
SWM	stormwater management
TM	technical memorandum

SECTION 1

Introduction

The City of Alexandria, Virginia has experienced repeated and increasingly frequent flooding events attributable to old infrastructure, inconsistent design criteria, and perhaps climate change. The purpose of the stormwater capacity analysis project is to provide a program for analyzing storm sewer capacity issues, identifying problem areas, developing and prioritizing solutions, and providing support for public outreach and education. The project is being implemented in phases by watershed, starting with Hooffs Run, which is the subject of this TM. City of Alexandria watersheds are shown on Figure 1-1.

1.1 Background

The project consists of four major subtasks related to the model development and modeling. These four tasks and related TMs are described below.

- Task 1 – Review and propose revisions to the City's stormwater design criteria.
  - *Updated Precipitation Frequency Results and Synthesis of New IDF Curves for the City of Alexandria, Virginia* (CH2M HILL, 2009a)
  - *Sea Level Rise Potential for the City of Alexandria, Virginia* (CH2M HILL, 2009b)
  - *Rainfall Frequency and Global Change Model Options for the City of Alexandria* (CH2M HILL, 2011)
- Task 2 – Analyze the City's stormwater collection system capacity.
  - *Inlet Capacity Analysis for City of Alexandria Storm Sewer Capacity Analysis* (CH2M HILL, 2012)
  - *Stormwater Capacity Analysis for Hooffs Run Watershed, City of Alexandria, Virginia* (CH2M HILL, 2016)
- Task 3 – Survey collection system facilities on pipes 24 inches and larger to fill data gaps.[1]
  - *City of Alexandria Storm Sewer Capacity Analysis Task 3.1 – Pilot Study Area Field Verification – Survey and Inspection* (Baker, 2010)
- Task 4 – Identify problem areas and suggest solutions.
  - *Task 4 Evaluation Criteria Scoring Systems* (CH2M HILL, 2014)

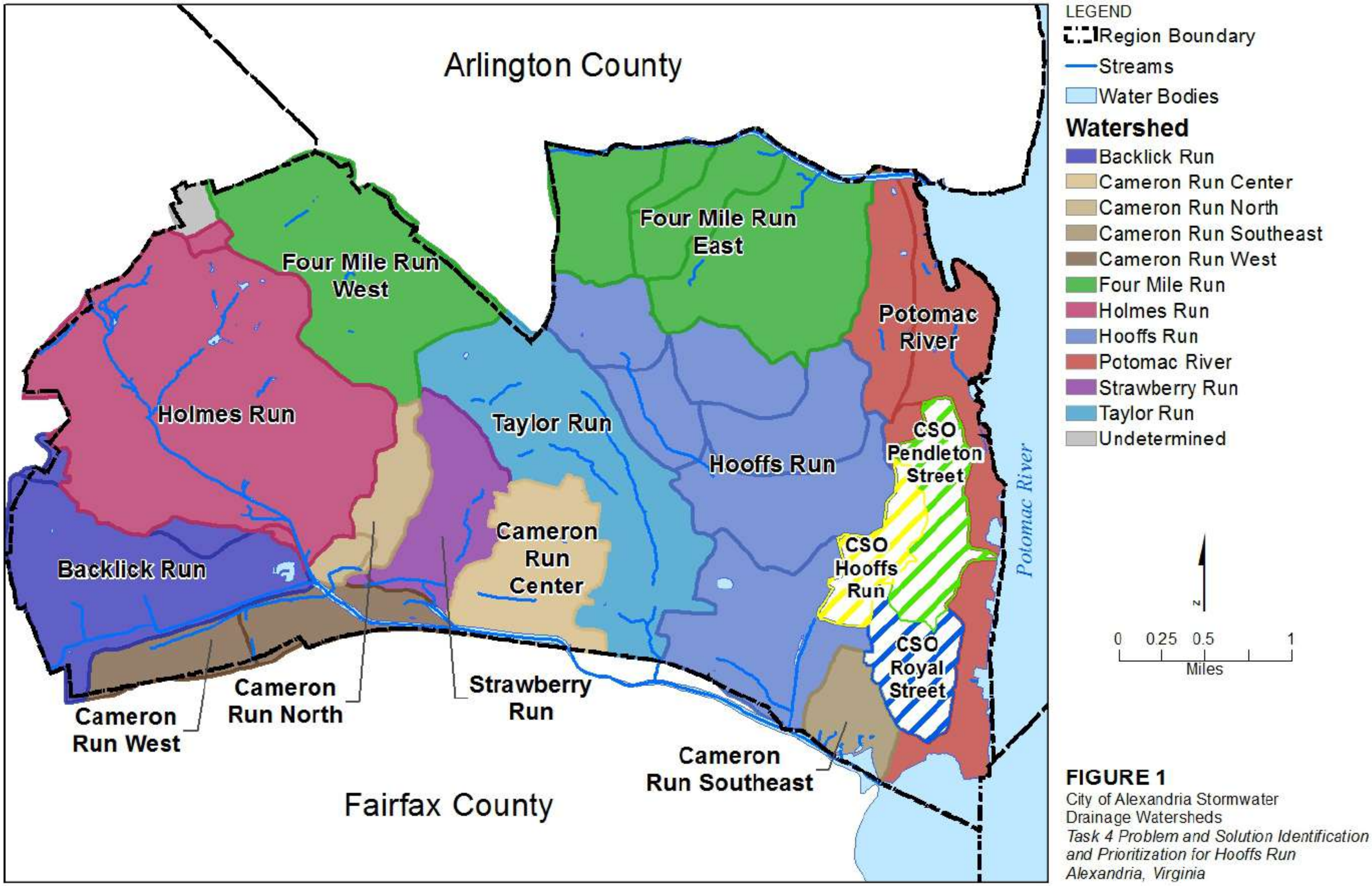
1.2 Objectives

Tasks 1 through 3 focused on model development and capacity analysis of the existing system. The purpose of Task 4 is to identify and prioritize problems modeled during the Task 2 capacity analysis and to suggest and prioritize conveyance, conventional SWM, and green infrastructure solutions to resolve the identified capacity limitations.

This TM describes the methodology and results of Task 4 for the stormwater collection system in the Hooffs Run Watershed. Subsequent memoranda will describe the results for remaining watersheds in the City. Figure 1-1 presents the City of Alexandria's stormwater drainage watersheds.

[1] Though originally intended to improve data quality where the model predicted capacity limitations, the scope of Task 3 was expanded, and field survey was completed prior to Task 2 to fill data gaps and to improve the model development process.

FIGURE 1-1
Stormwater Drainage Watersheds, City of Alexandria, Virginia
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



SECTION 2

Approach

The approach to identifying and prioritizing problems and solutions included several distinct steps: identification and prioritization of problems, development and modeling of solutions, prioritization of solutions and, finally, development of watershed-wide scenarios. This approach, described in this section, is broken into two major components: prioritization and modeling.

2.1 Prioritization

The focus of Task 4 is prioritization of problem areas based on Task 2 modeling results, development of solutions to resolve the problem areas, then prioritization of solutions. Prior to beginning the Task 4 analysis, City of Alexandria staff and consultants from CH2M HILL and Michael Baker convened in a workshop on November 14, 2012 to discuss the objectives, approach, and desired outcomes of this phase of the project. The major objectives of the workshop were to define the prioritization process, identify the key evaluation criteria for scoring and ranking problems and solutions, and define relative criteria weights. The prioritization process, described below, is similar for both problems and solutions and includes several distinct steps.

- **Define evaluation criteria**: Evaluation criteria for problems and solutions were defined during the Task 4 workshop with input from City of Alexandria staff from the Engineering & Design, Office of Environmental Quality, and Maintenance Divisions of Transportation and Engineering Services. These criteria, which are summarized in this TM, were used to assess the severity of problems and the benefit of solutions.
- **Weight evaluation criteria**: Each evaluation criterion was assigned a weight (0 to 100) by Task 4 workshop participants. The weights quantify the relative importance of each evaluation criteria and build a defensible foundation for problem and solution ranking.
- **Define scoring system**: A scoring system was developed for each evaluation criteria. This provided a method for ranking problems and solutions within evaluation criteria. Scoring systems for problem area and solution evaluation criteria are defined in this TM.
- **Score and rank alternatives**: Problems and solutions were scored and ranked using the evaluation criteria scoring systems, which are described in the TM entitled *Task 4 Evaluation Criteria Scoring Systems* (CH2M HILL, 2014) and include:
    - *Score and Rank Problems:* A score of 0 through 10 was assigned to stormwater junctions in the modeled system for each evaluation criteria. Weights were then applied to the score calculated for each evaluation criteria to come up with an overall weighted score for each junction. The overall score was used to rank problems, and then high-priority problem areas were identified as groupings of hydraulically connected junctions and pipes. Solutions were investigated for the highest-priority problem areas.
    - *Score and Rank Solutions*: Solutions were developed for high-priority problem areas identified in the previous step. A score of 0 through 10 was assigned to solutions for each evaluation criteria. Then the weights were applied to the score calculated for each evaluation criteria to calculate an overall weighted benefit score. Solutions were ranked based on the overall score as well as the cost/benefit score, which is the overall benefit score divided by the capital cost of the solution. The solution evaluation is presented at the end of this TM.
- **Perform "what-if" analysis to refine process**: After completing the prioritization, the process was examined to ensure the results met the expectations of the City. The outcome of this step was the inclusion of a 22 percent minimum threshold for flood volume reduction (any project that produced less than 22 percent reduction in volume of flooding was eliminated) to help focus the solution identification process. This threshold was selected by City of Alexandria staff based on best engineering judgment.
- **Evaluate watershed-wide scenarios**: Once individual solutions were evaluated, the solutions were grouped into three alternative watershed-wide scenarios. The scenarios were scored by summing scores and costs of

individual projects for comparison. The purpose of taking this watershed-wide look at solution sets was to evaluate the solutions in a holistic, system-wide manner to evaluate composite impacts of implementing various solutions across the system and to support selection of a set of solutions that will provide the greatest benefit for the most efficient cost.

2.1.1 Problem Area Evaluation

The problem area evaluation focused on identifying flooding problems that are extreme and/or in proximity to critical facilities. Though model results were presented for pipes, not junctions, in the Stormwater Capacity Analysis (Task 2), flooding occurs at a junction and not along the length of the pipe; therefore, stormwater junctions in the hydraulic model, not pipe segments, were scored for each of the problem area evaluation criteria. Raw scores for each criterion ranged from 0 to 10, 0 indicating the junction is not a priority and/or the evaluation criteria is not applicable, and 10 indicating the junction is a high priority. The problem area evaluation criteria include:

- Urban drainage/flooding
- Identification of problems by the public
- Identification of problems by city staff
- Proximity to critical infrastructure
- Proximity to critical roadways
- Opportunity for overland relief

Detailed descriptions of the problem scoring systems used in this evaluation are provided in the TM entitled *Task 4 Evaluation Criteria Scoring Systems* (CH2M HILL, 2014). The weighted score was computed using the raw score and normalized percent weight. Evaluation criteria and weights developed and agreed upon during the Task 4 Workshop are presented in Table 2-1.

TABLE 2-1
Problem Area Evaluation Criteria and Weights
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Problem Area Evaluation Criteria	Weight	Normalized % Weight
Urban Drainage/Flooding	90	23.1
Public ID of Problem	73	18.8
City Staff ID of Problem	75	19.3
Proximity to Critical Infrastructure	58	14.9
Proximity to Critical Roadways	38	9.8
Opportunity for Overland Relief	55	14.1
Total	**389**	**100**

Note:
ID = Identification

After computing the weighted score for each junction, high-priority problem areas were identified as hydraulically connected groupings of junctions and pipes for the junctions with scores in the top 33 percent of scores over 0. Scoring was based on results from the Task 2 model of the 10-year, 24-hour storm generated using the existing IDF curve. The results of the problem area evaluation are presented in the Problem Identification section.

The goal of delineating high-priority problem areas was to identify groupings of stormwater pipes causing capacity limitations so that conveyance, conventional SWM, and green infrastructure solutions could be developed for the area. This task was accomplished by starting with the highest-ranked junction score, which indicated it was the worst problem based on the problem area identification evaluation criteria, and reviewing the surrounding drainage network and model results to identify the pipes and junctions related to that high problem score. A polygon surrounding all the pipes related to the capacity limitation was digitized in ArcMap and was assigned a unique identifier. After completing this process for the highest-ranked junction score, the network and model results for the next-highest score were examined, and a new problem area was digitized; however, if the junction with the next highest-score was already captured in the first high-priority area, it was skipped. This process was repeated for junctions with a score above 35, or the top 33 percent of junctions with a score over 0.

2.1.2 Solution Evaluation

Solutions were developed to resolve or improve capacity limitations in the highest-priority problem areas. Three different technologies were evaluated: conveyance, conventional SWM, and green infrastructure. Modeling results, described in detail in the following sections, were used in conjunction with additional data from the City (for example, geospatial data on roads and critical infrastructure, capital improvement plans, maintenance plans) to score solutions for each of the following solution evaluation criteria:

- Urban drainage/flooding
- Environmental compliance
- EcoCity goals/sustainability
- Social benefits
- Integrated asset management
- City-wide maintenance implications
- Constructability
- Public acceptability

Detailed descriptions of the solution scoring systems used in this evaluation are provided in the TM entitled *Task 4 Evaluation Criteria Scoring Systems* (CH2M HILL, 2014). The weighted score was computed using the raw score and normalized percent weight. Evaluation criteria and weights agreed upon during the Task 4 workshop are presented in Table 2-2.

TABLE 2-2
Solution Evaluation Criteria and Weights
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Solution Evaluation Criteria	Weight	Normalized % Weight
Urban Drainage/Flooding	95	17.1
Environmental Compliance	93	16.8
EcoCity Goals/Sustainability	50	9.0
Social Benefits	40	7.2
Integrated Asset Management	73	13.2
City-wide Maintenance Implications	90	16.2
Constructability	60	10.8
Public Acceptability	53	9.6
Total	**554**	**100**

2.2 Modeling

To support the Task 4 analysis, the Hooffs Run Watershed capacity was analyzed using commercially available and public domain computer models widely used and industry-accepted. The details of the hydrologic and hydraulic modeling are documented in the Task 2 TM, *Stormwater Capacity Analysis for Hooffs Run Watershed, City of Alexandria, Virginia* (CH2M HILL, 2016). The existing conditions model of the 10-year, 24-hour design storm based on the City’s existing IDF curve served as the basis for modeling in the Task 4 analysis. Several modifications were made to the Task 2 model before evaluating potential solutions. First, because the city is being modeled one watershed at a time, the modeling approach is being refined with each new watershed, and as such, a few amendments were made to the model before proceeding with identifying problems and solutions. These model refinements are described below.

Additionally, in some cases, significant jumps in the hydraulic-grade line (HGL) were identified that were due to short lengths of sudden diameter or slope change that could be a data error. Baseline improvements were defined for these areas that may or may not be necessary projects. In other locations, there were extreme capacity limitations that had a long backwater impact. This backwater impact made it difficult to evaluate upstream alternatives. Major conveyance projects were identified to resolve these long impacts prior to evaluating solutions for the rest of the watershed. After completing baseline improvements and developing major capacity solutions, the solution alternatives were modeled in xpswmm.

2.2.1 Task 2 Model Refinements

Several changes were made to the Task 2 model before beginning the Task 4 work of identifying problems and solutions. The first change was to simplify the model by removing storage junctions at manholes on pipes 36 inches in diameter and larger. These storage junctions were originally included in the model at the request of the City to simulate the storage that occurs in junction boxes between two larger-diameter pipes. However, there were issues identified with the use of storage nodes in combination with allowing ponding in xpswmm. The top of the storage is set to the rim of the node, which is also the spill crest. The intent was to store any surcharged flow inside the manhole up to the rim elevation and then—using the ponding “Allowed” option in xpswmm—store flooded volume aboveground until the system has capacity to convey the flow. If ponding is not allowed, flow is “lost” from the system once it rises above the spill crest.

However, in xpswmm, when ponding is “allowed,” the invert elevation of the storage node is set at the spill crest elevation, and the spill crest is set to the original spill crest plus the maximum depth specified for the storage node. In other words, the storage is aboveground with a standard manhole below. Since there is no maximum depth for constant area storage, which is how junction storage was being modeled, the manhole is infinitely high. As such, flow is not “lost” from the system, but the HGL continues rising unrealistically. Because the storage provided by larger manholes is small relative to the pipe sizes around it, it was determined that eliminating the storage function would have a lesser impact on the model than turning off the ponding and losing flow from the model.

Additionally, entrance and exit loss values were adjusted in the hydraulic model. Closer review of xpswmm computations revealed that the model does not take downstream velocity into consideration when computing entrance and exit losses on pipes. Because xpswmm is not accounting for the downstream velocity, the model assumes flows are entering a reservoir, which overestimates headloss. To compensate for this nuance, entrance losses were lowered to 0.1 from 0.5, and exit losses were lowered to 0.15 from 1.0.

Lastly, two large catchments draining the railroad tracks and right of way (ROW) were set up to discharge to an open pipe inlet (000543IO) near the intersection of Leslie and Glendale Avenues in the Task 2 model. Review of the results showed that these two large catchments were contributing excessive runoff to the drainage network, causing flooding and capacity limitations downstream along Monroe Street. Closer inspection of the topography revealed that these catchments did not appear to drain into Hooffs Run and were consequently disconnected from the hydrologic model for the Task 4 modeling efforts.

Figure 2-1 and Table 2-3 present the revised Task 2 results based on the refinements described above.

FIGURE 2-1
Revised Task 2 Model Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

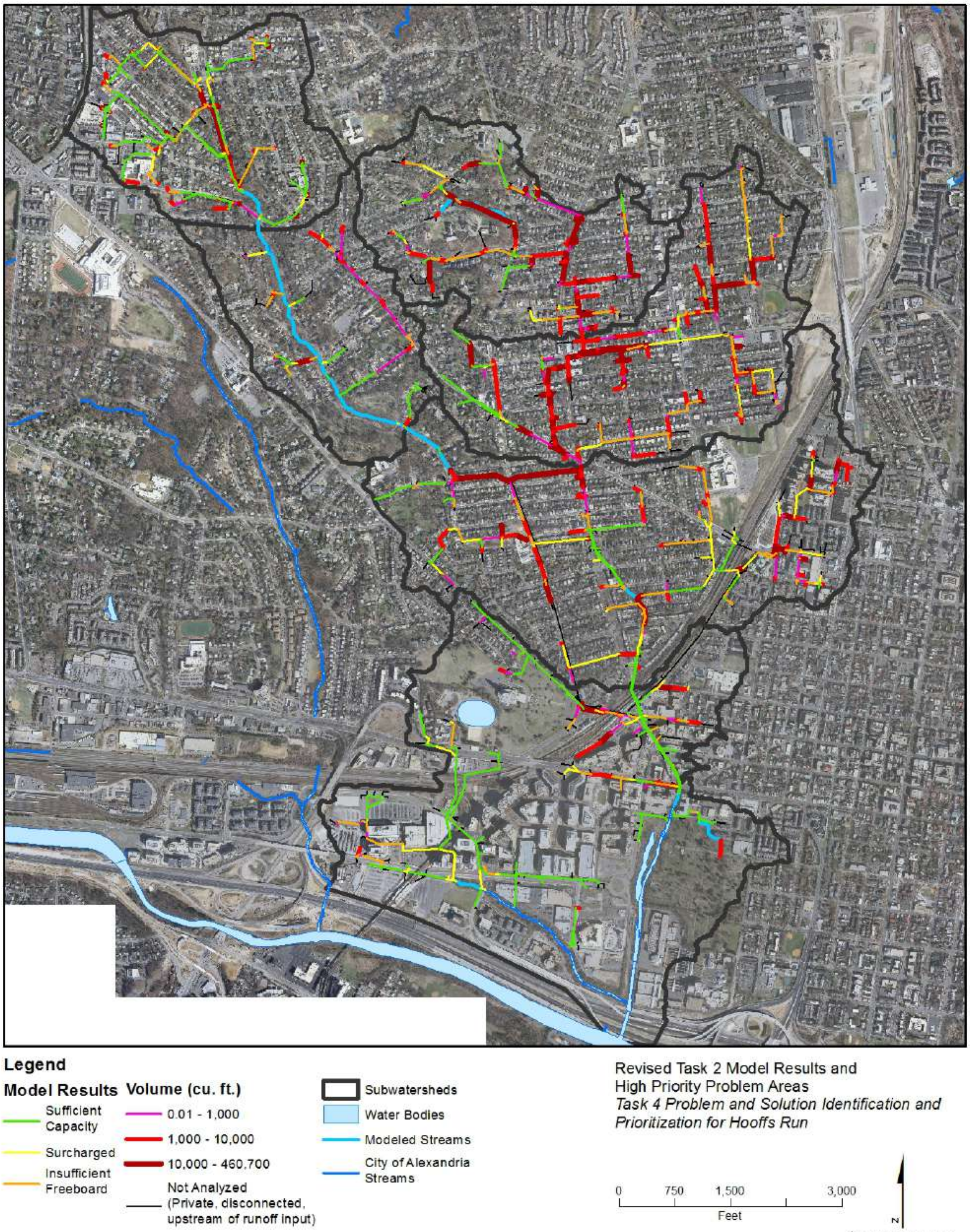


TABLE 2-3
Summary of Revised Task 2 Model Results in Hooffs Run
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

	Major Capacity Results			
	Conduit Length (LF)	**Percent of Total Length (%)**	**Total Duration (hrs)**	**Total Volume (ft^3)[b]**
Sufficient Capacity	45,379	32	-	-
Surcharged[a]	17,146	12	1,967	-
Insufficient Freeboard	26,705	19	-	-
Flooded	50,950	36	922	6,070,365

Notes:
Results presented for pipe segments are based on capacity at upstream end of pipe.
[a] Duration of surcharged flow includes time during which conduits have insufficient freeboard or are flooded at upstream end only.
[b] Flooded volume includes volume flooded at upstream end of the conduit.

2.2.2 Baseline Improvements

The goal of identifying baseline improvements was to remove hydraulic limitations that may have negatively impacted the ability to model solutions. Significant jumps in the HGL due to potential data errors or short lengths of sudden diameter or slope change may cause or exacerbate flooding in upstream problem areas. To better assess where there are significant problems in the drainage network and to develop efficient solutions for those problems, it was beneficial to eliminate small hydraulic limitations before proceeding with developing alternative solutions.

Profiles of the Hooffs Run existing conditions model results were reviewed to identify significant changes in diameter or slope over relatively short distances where there was also a sudden increase in the HGL. In addition to reviewing the profiles, the data source for invert and diameter information was reviewed. Due to limited survey efforts in the Hooffs Run watershed or difficult access to some areas, not all of the identified baseline improvement areas were surveyed. Overall, nine locations were identified as requiring baseline improvements, and the model was adjusted to remove the identified limitations. These nine locations and project capital costs are described in Table 2-4, and profiles are provided in Appendix A. The identification of a baseline project indicates either a data error that could not readily be resolved within the scope of this project or an actual short hydraulic restriction that should be addressed. Further field investigations are recommended at these locations to obtain accurate information and determine if projects are warranted.

TABLE 2-4
Summary of Baseline Improvements
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Baseline Project	Issue	Resolution	Project Length (LF)	Project Capital Cost ($)
1	Neck down	Increase diameter of 006817STMP, 014021STMP, 014906STMP, 004915STMP to 2.5 feet to match next upstream pipe (014020STMP)	185	$71,147
2	Neck down	Eliminate neck down by increasing diameter of 006873STMP to 5 feet to match next downstream pipe (006942A)	44	$36,437
3	Neck down	Eliminate neck down by increasing pipe diameter of 007006STMP to 4 feet to match next downstream pipe (007005STMP)	415	$275,595
4	Reverse slope	Adjust slope of 010248STMP, 010246B, 010246A to be consistent between next upstream and downstream pipes (010249A and 010236STMP respectively)	174	$45,964
5[a]	Neck down	Increase diameter of 009315STMP and 009317STMP to 3.5 feet to match next upstream pipe (010483STMP)	56	$32,358

TABLE 2-4
Summary of Baseline Improvements
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

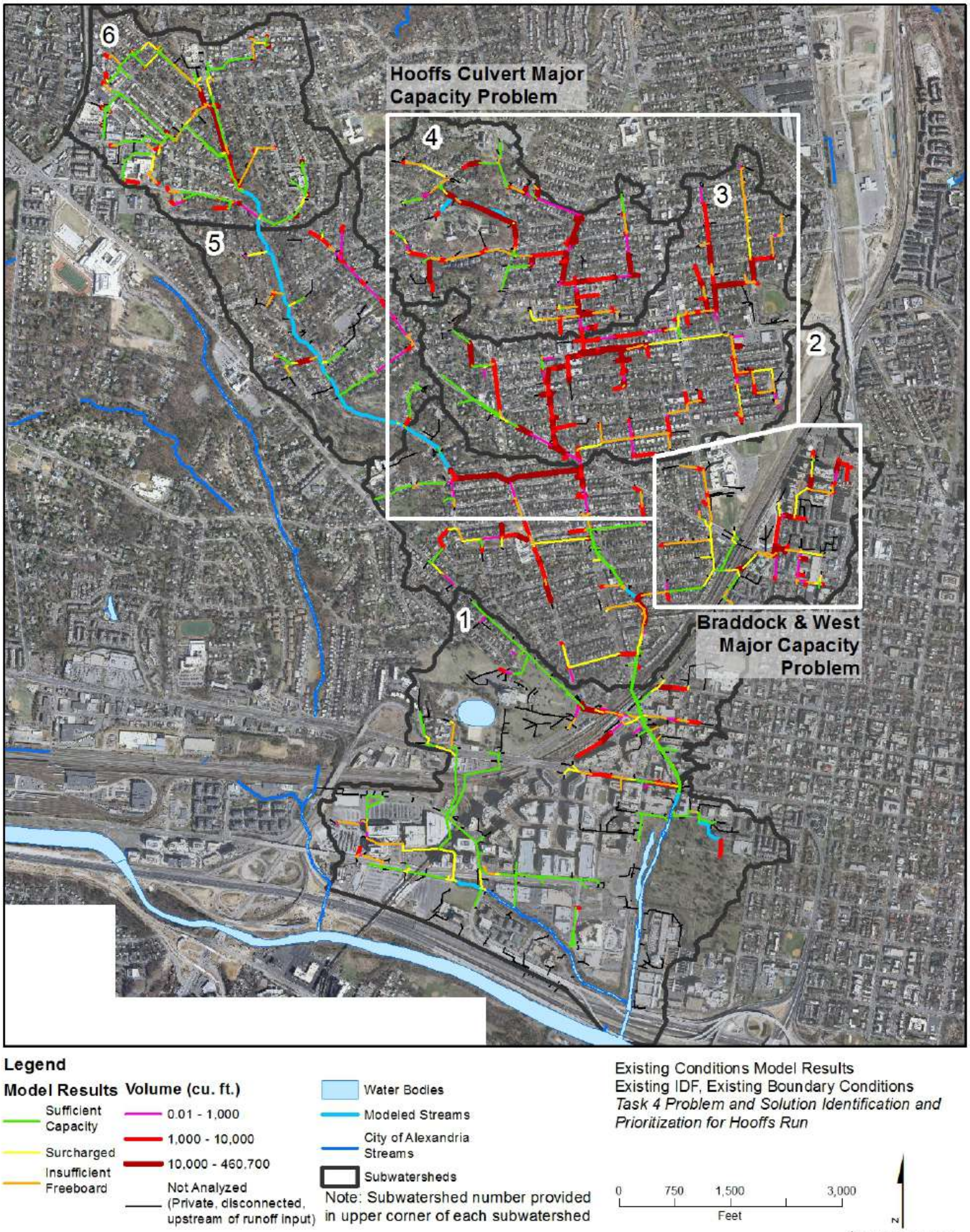
Baseline Project	Issue	Resolution	Project Length (LF)	Project Capital Cost ($)
6	Steep slope, neck down, and reverse slope	Assume straight line slope between downstream ends of 009366STMP and 008410STMP and increase diameter of 010572A, 010572B, and 008410STMP to 2 feet to match next downstream pipe (008409STMP)	451	$99,043
7	Odd configuration	Adjust slope to be constant between 010444STMP and 010441STMP NOTE: This area was not surveyed therefore it will be listed as a baseline project but is specifically called out as requiring field verification.	162	$31,114
8[a]	Neck down and reverse slope	Increase pipe diameter of 010614STMP, 010617STMP, 010618B, 010618A, and 009482STMP to 3.5 feet to match downstream and upstream pipe diameters (010613STMP and 009517B respectively). Smooth slope between 010613STMP and 009517B (about 0.686%). Adjust size and slope of 009483STMP, located between 009482STMP and 009485STMP.	190	$107,625
9	Neck down	Increase diameter of 009483STMP to 3.5 feet to match changes downstream. Adjust slope of 009483STMP to be a straight line between 009483STMP and 009519B (009519B has the lowest invert at manhole 003170SMH). Increase diameter of 009485STMP to match upstream pipe (009486STMP).	233	$128,229

Note: All project capital costs are in 2013 dollars.
[a] Some portion of the site was surveyed for this project

2.2.3 Major Capacity Solutions

In Hooffs Run there are two locations where extreme capacity limitations cause long backwater conditions and substantial flooding in the system: (1) Hooffs Culvert between Chapman Street and Monroe Street and (2) the intersection of Braddock Road and West Street. The location of these two areas and the extent of the flooding and backwater are shown on Figure 2-2. Due to the extreme nature of the capacity limitations in these locations and the dendritic layout of the drainage network, analyzing problem areas and potential solutions upstream of these locations would be exceedingly difficult without improving the capacity in the system. For this reason, solutions were developed to improve or resolve the backwater issues and flooding in these two locations so that problems and solutions in upstream areas could be better assessed. These solutions are described in detail in the Major Capacity Projects section of this TM.

FIGURE 2-2
Location of Major Capacity Problems and Extent of Flooding and Backwater in the Existing Conditions Model
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



2.2.4 Alternative Solutions

The purpose of this task was to identify and evaluate corrective measures that could be undertaken to reduce flooding and pollutant load and to achieve other ancillary benefits such as improved aesthetics, urban-heat-island reduction, and carbon capture through context sensitive solutions. Potential solutions were developed for each of the following project types or technologies, where applicable:

- Conveyance improvements
- Conventional SWM (modeled as storage)
- Green infrastructure

The goal of the conveyance solutions was to evaluate the impact of increased conveyance capacity on flooding and surcharge in the high-priority problem areas. Conveyance improvements were modeled in xpswmm by increasing pipe diameter up to 0.1 foot below ground surface (bgs). The invert elevations and alignment of existing pipes were not altered, so pipe slope did not change from existing conditions. Since the goal of this evaluation was not to design solutions but to evaluate potential strategies and technologies, more detailed design will be required to develop fully implementable projects, including adjusting pipe shapes, providing parallel pipes, and providing for adequate ground cover.

The conventional SWM solutions involved evaluating potential for new detention or retention facilities or inline storage for high-priority problem areas. Due to the dense urban development prevalent in the City, conventional SWM practices were assumed to be limited to subsurface storage facilities in the hydraulic model. Opportunities for subsurface storage were identified in open spaces, such as parking lots, green spaces, and grassed medians, with a preference for City-owned properties. Storage was modeled in xpswmm using storage nodes and weirs to model the overflow from a manhole into storage. The maximum storage size was determined by measuring the surface area of the open space available for storage and estimating the storage depth based on the manhole to which the storage system would be dewatered. It was assumed that storage should be a minimum of 3 feet deep and a maximum of 10 feet deep to maintain reasonable construction costs. Additionally, storage was only considered if gravity dewatering to a manhole within 1,000 feet was possible. Storage facilities would not be dewatered until the system had capacity to convey the stored flow. As such—and considering the focus of the modeling was to identify capacity limitations and flooding problems—storage dewatering was not evaluated in this analysis.

Green infrastructure was evaluated at three different implementation levels: low, medium, and high. In the xpswmm model, green infrastructure was modeled by reducing impervious cover in model subcatchments. The low implementation level was modeled as a 10 percent reduction in impervious area, the medium at a 30 percent reduction, and the high at a 50 percent reduction. Soils and depression storage parameters were evaluated for sensitivity in the model. Ideally, these parameters would be adjusted to more accurately represent the physics of green infrastructure performance in the field. However, this level of detail in modeling was beyond the scope of this study, and infiltration parameters were not altered when modeling green infrastructure.

Table 2-5 describes the modeling approach and basic assumptions for each of the solution technologies. Solutions developed for each high-priority problem area are described in greater detail in the Solution Identification section of this TM.

TABLE 2-5
Description of Solution Modeling Approaches and Assumptions
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Solution Technology/Strategy	Modeling Approach	Basic Assumptions
Conveyance	Increase Pipe Diameter	Use existing slope and pipe alignment. Increase pipe diameter to a maximum of 0.1 foot bgs. Add barrels as necessary.
Conventional SWM/ Storage	Add storage node with weir to convey flow into storage	Storage depth is between 3 feet and 10 feet bgs. Gravity dewatering is required. A 20-foot-long weir to storage with discharge coefficient of 3 is required. Only surcharged flow will be sent to storage.
Green Infrastructure	Decrease catchment impervious area	Low implementation: 10 percent reduction in impervious area. Medium implementation: 30 percent reduction in impervious area. High implementation: 50 percent reduction in impervious area.

Solution alternatives were modeled in xpswmm. The basis for the solution models was the Task 2 existing conditions model with the addition of baseline improvements and a major capacity projects for Hooffs Culvert and Braddock Road and West Street. This approach allowed for better evaluation of the benefit of the solution alternatives in the absence of smaller bottlenecks caused by potential data errors, as well as long backwater and extreme flooding due to the major capacity limitations in Hooffs Run.

Using the model containing baseline improvements and major capacity projects, alternative solutions were evaluated in five different models, one for each technology/strategy:

- Conveyance solutions model
- Storage solutions model
- Low green infrastructure implementation model
- Medium green infrastructure implementation model
- High green infrastructure implementation model

This approach has limitations. First, several projects are in proximity to one another; therefore, the hydraulics are inextricably linked. However, due to the number of solutions and technologies being evaluated, evaluating each project independently was not within the scope of the analysis.

Additionally, the baseline improvements and major capacity projects heavily influence the results for most of the high-priority area solutions. Without including the two diversions (Hooffs Culvert and Braddock Road and West Street), several of the solutions may not appear to be as favorable. This is because the long backwater and excessive flooding caused by a significant capacity limitation in a central location has the potential to mask the benefits of small scale, localized hydrologic and hydraulic improvements in the model. Modeling solutions without the backwater caused by the major capacity problems allows for better evaluation of the ability of high-priority problem area solutions to resolve localized flooding and capacity limitations.

SECTION 3

Major Capacity Projects

Modeling results from the Task 2 capacity analysis revealed two locations in Hooffs Run that cause long backwater conditions and substantial flooding in the system: Hooffs Culvert and the intersection of Braddock Road and West Street. Conveyance and conventional SWM alternatives were developed for each of the two major capacity problems. Subsurface storage was the conventional SWM alternative considered due to the lack of available space above ground for detention or retention SWM practices. Green infrastructure was considered, but a sensitivity model run with 0 percent impervious across the watershed did not resolve the major capacity limitations. The goal of these solutions was to reduce flooding and backwater to provide a better starting point for evaluating solutions for remaining flooding in the high-priority problem areas. While constructability was considered, the solutions identified during this phase of the analysis are considerable in size and scope and would require more detailed planning and analysis to assess the overall feasibility and constructability. The solutions were modeled in two separate model runs in xpswmm: one for the storage solutions and one for the conveyance solutions.

Planning-level capital costs were developed for the conveyance and storage solutions. However, the major capacity solutions were not scored during the alternatives analysis portion of this evaluation since the primary goal of developing these major capacity projects was to reduce downstream capacity constraints that mask upstream capacity limitations during design storm conditions. By reducing these major bottlenecks, solutions could be better evaluated in areas still flooded after removal of backwater from these substantial capacity limitations.

It is important to note that the existing conditions model is predicting extreme flooding and backwater in these locations in part because the model is conservative both in terms of the peak and volume of the 10-year, 24-hour design storm, and the storm is applied across to the entire watershed uniformly. This means that the entire Hooffs Run system is being inundated with a 10-year peak flow at the same time. In reality, storm systems move across watersheds, and storm conditions vary across the watershed. In addition, as discussed in previous reports, capacity limitations of the surface inlets are not included in the model. Surface storage resulting from these limitations could reduce flow into the system and this has not been accounted for in the model, adding to the conservative nature of the model.

Detailed descriptions and model results and capital costs of the major conveyance and storage solutions are provided in the following subsections. Capital costs were estimated using assumptions described in the Alternatives Analysis and Prioritization section of this TM. Additionally, CH2M HILL reviewed alternatives proposed in the drainage improvement studies for Hooffs Run (AMT, 2008a) and Braddock Road and West Street (AMT, 2008b). Costs developed during these two drainage improvement studies are included in the following subsections where the solution modeled during the Task 4 work had a direct comparison in the drainage improvement studies.

3.1 Hooffs Culvert

Hooffs Culvert is the central artery of the Hooffs Run Watershed. Stormwater runoff from the majority of the watershed is directed to the box culvert, which begins as a single 4-foot by 7-foot barrel near the intersection of Bellefonte and Commonwealth Avenue and discharges to the Hooffs Run open channel just south of Duke Street as a double-barrel culvert with 6.5-foot by 17-foot and 6.5-foot by 21-foot boxes. The culvert transitions from a single- to a double-barrel culvert (each barrel is 5 feet by 15 feet at the transition) near the intersection of Chapman and Commonwealth Avenues. Just upstream of the transition to a double barrel near Spring Street and Commonwealth Avenue, the culvert receives flow from a 5-foot by 8-foot culvert conveying runoff from Timber Branch. The location of the single-barrel culvert and Timber Branch inflows are shown on Figure 3-1.

During the 10-year, 24-hour design storm, the peak flow from Timber Branch is approximately 700 cubic feet per second (cfs). This large peak discharge along with a peak flow of about 500 cfs from Hooffs Run Subwatersheds 3 and 4 (see Figure 2-2) cause substantial flooding and backwater upstream of the transition to a double barrel.

CH2M HILL reviewed the Drainage Improvement Studies for Hooffs Run (AMT, 2008a) made available by the City prior to developing alternatives for this location. Alternatives to mitigate flooding developed during previous studies included:

- Alternative A - a new 7,822 ft gravity sewer system to the Potomac River
- Alternative B - a new 11,709 ft gravity sewer to Cameron Run
- Alternative C - a new diversion to a 1MG tank George Washington Middle School athletic fields with pump out to the Potomac River
- Alternative D - replacement of the existing box culvert with an open channel

CH2M HILL evaluated variations of Alternatives B and C.

3.1.1 Major Storage Solution

Due to the limited availability of open space in the vicinity of Hooffs Culvert, the athletic field at George Washington Middle School was the closest available opportunity for below grade storage. A diversion from the single-barrel culvert at the location of the Timber Branch connection conveys the peak overflow approximately 2,100 feet eastward along E. Spring Street and then south on Mt. Vernon Avenue to the school's athletic fields. The athletic field is approximately 250,000 square feet (ft^2), and storage depth was assumed to be 10 feet. Due to the depth of the culvert and the distance between the diversion and the athletic field, 18 feet of excavation would be required to achieve 10 feet of storage depth.

Modeled in this way, the system would utilize approximately 13 million gallon (MG) of storage. The diversion pipe and storage node location are shown in Figure 3-2. The estimated capital cost for this project is approximately $ $18.5 million based on the costing approach described in the Alternatives Analysis and Prioritization section of this TM. Although this is similar in concept to Alternative C, evaluated in the Drainage Improvement Study for Hooffs Run (AMT, 2008a), the solution in the drainage study included a much smaller tank, with a pump out to the Potomac River, with a capital cost of $46 million (approximately $54 million in 2013 dollars).

Due to the extreme volume of runoff generated during the 10-year, 24-hour storm, storage is not considered a feasible alternative for Hooffs Culvert due to cost and constructability implications. However, this alternative was modeled to determine whether flooding and backwater problems could be significantly improved with a storage solution. Model results are presented at the end of this section.

FIGURE 3-1
Hooffs Culvert Single Barrel Culvert Location
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

FIGURE 3-2
Hooffs Culvert Storage Solution Configuration
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

3.1.2 Major Conveyance Solution

As stated above, the Hooffs Culvert receives a peak flow of almost 700 cfs from Timber Branch under the existing conditions. A model was run to simulate unconstrained peak flow where all pipes in the model were increased to 0.1 inch bgs, and the number of barrels was increased by a factor of 2. The unconstrained model run was used to remove upstream constraints and to ensure proposed projects were sized with sufficient capacity to accommodate upstream conveyance improvements. This model run resulted in a peak over 1,000 cfs from Timber Branch. The peak flow coming down the Hooffs Culvert from Subwatersheds 3 and 4 upstream of the Timber Branch connection is about 450 cfs under existing conditions and about 1,200 cfs under unconstrained conditions. The full flow capacity of the single barrel of Hooffs Culvert is approximately 750 cfs under gravity-flow conditions. In an attempt to reduce flows in the Hooffs Run Culvert to closer to gravity-flow capacity, the flow from Timber Branch was diverted down Russell Road in a new 6-foot by 10-foot box culvert approximately 4,700 feet long that discharges into the western barrel of Hooffs Culvert near the intersection of Commonwealth Avenue and King Street, where there is capacity within the existing culvert. Figure 3-3 shows the layout of the modeled diversion. Model results are presented at the end of this section. The capital cost estimate for this solution is approximately $13.6 million. Although this is similar in concept to Alternative B evaluated in the Drainage Improvement Study for Hooffs Run (AMT, 2008a), the solution in the drainage study extended the pipe to Cameron Run, for a total length of 11,709 feet, with an estimated capital cost of $64 million dollars (approximately $76 million in 2013 dollars).

FIGURE 3-3
Hooffs Culvert Major Conveyance Solution
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

3.2 Braddock and West

The intersection of Braddock Road and West Street has well-known flooding issues that have been studied by the City at great length. CH2M HILL reviewed the drainage improvement studies for Hooffs Run (AMT, 2008a) and Braddock Road and West Street (AMT, 2008b) made available by the City prior to developing alternatives for this location. Alternatives to mitigate flooding developed during previous studies included:

- Alternative 1: 4,225 LF gravity sewer system along West and Peyton Street
- Alternative 2: 4,069 LF gravity diversion to the Potomac River
- Alternative 3: 4,565 LF force main diversion to Hooffs Run
- Alternative 4: 4,469 LF combination of gravity and force main diversion to the Potomac River
- Alternative 5: subsurface storage under George Washington Middle School athletic fields

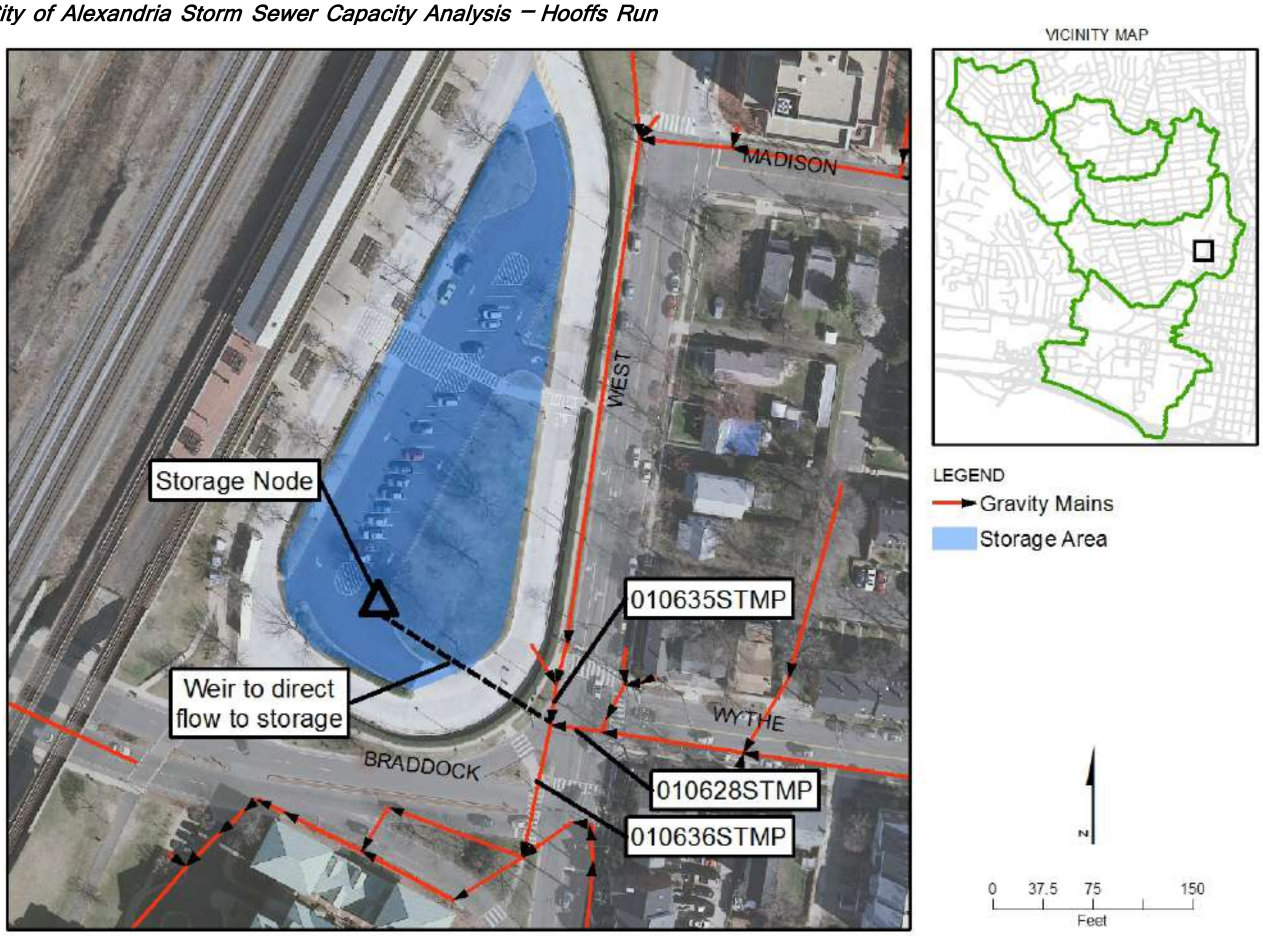
Review of the available data and existing conditions model results revealed that several factors contribute to the flooding problem. There are multiple locations where a larger-diameter pipe discharges to a smaller-diameter pipe, most notably just before and under the railroad tracks. Due to the location in the railroad and railroad ROW, invert and diameter data in this location are difficult to verify. Additionally, model results show that pipe 010636STMP (2-foot-diameter pipe) just upstream of the intersection, shown on Figure 3-4, does not have sufficient capacity to handle the existing flow coming from 010635STMP (2-foot-diameter pipe conveying flow along West Street from the north) and 010628STMP (2-foot-diameter pipe conveying flow along Wythe Street from the east), exacerbating flooding in the vicinity and impacting backwater upstream of the intersection. A depression in the ground surface elevation in the intersection results in limited cover over the storm pipes, exacerbating flooding and compounding capacity limitations in the vicinity of Braddock Road and West Street.

CH2M HILL evaluated a variation of Alternative 5 for a storage solution, but considered a different conveyance alternative that utilized existing capacity in the Hooffs Run culvert downstream.

3.2.1 Major Storage Solution

The storage solution for Braddock Road and West Street, shown on Figure 3-4, used the space underneath the Braddock Metro Station parking lot, which has an area of approximately 56,000 ft^2. Previous studies indicated use of this property may not be feasible based on conversations with the property owner; therefore, storage was provided at George Washington High School on the other side of the railroad tracks. In order to simplify the hydraulic modeling, the storage was modeled at the Metro Station, but storage could be provided at either location with similar hydraulic results. The storage node was assumed to be 10 feet deep from the storage inlet, which provides a total storage volume of about 4.2 MG, although model results indicate the tank could be optimized to a 1.8 MG tank. The solution was modeled by adding a storage node with a constant area of 56,000 ft^2 connected to the system by a 20-foot-long weir to allow flow to overflow into the storage system without hydraulic limitation. The weir was placed at the upstream end of the pipe identified as being undersized, at the confluence of 010636STMP and 010628STMP. The capital cost for this solution is approximately $2.8 million. Although this is similar in concept to Alternative 5 evaluated in the Drainage Improvement Study for Braddock and West (AMT, 2008b), the solution in the two studies utilize different storage technologies and the Drainage Improvement Study assumes a longer conveyance distance. The capital cost of the facility in the Drainage Improvement Study is estimated to be approximately $10 to $14 million dollars (approximately $12 To $17 million in 2013 dollars). Model results are presented at the end of this section.

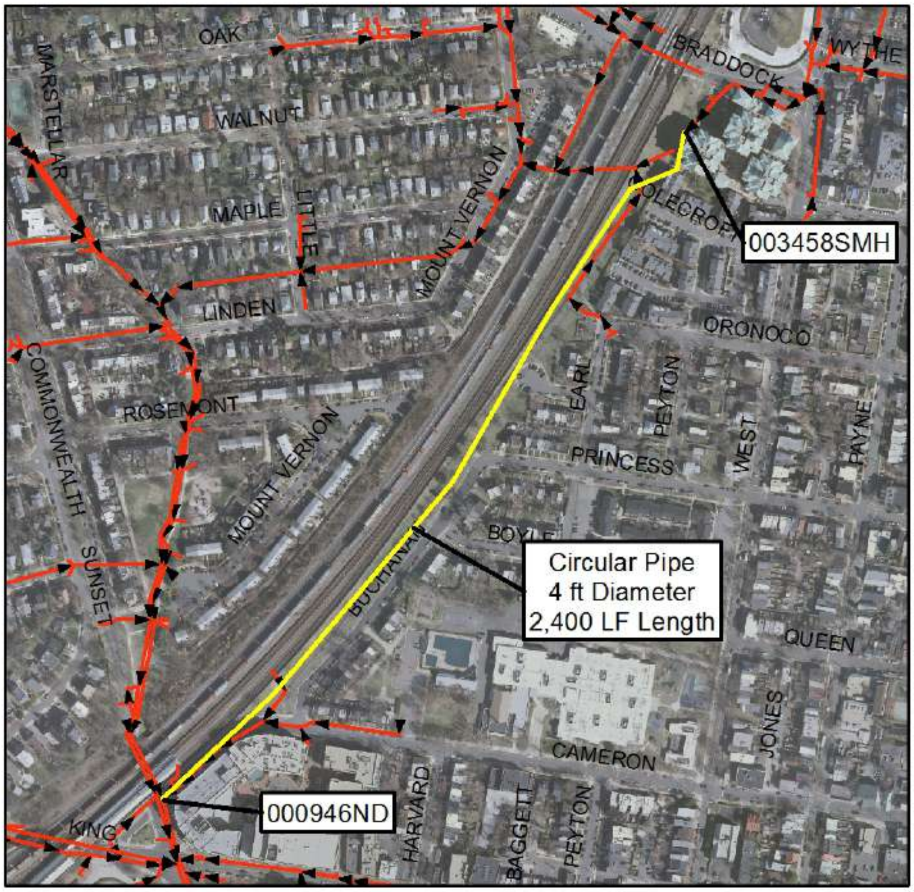
FIGURE 3-4
Braddock Road and West Street Major Storage Solution Configuration
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

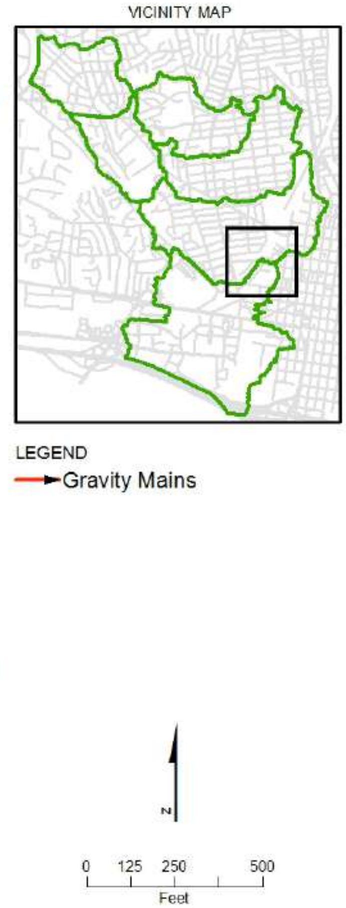


3.2.2 Major Conveyance Solution

The flooding in the intersection appears to be caused by neckdowns under the railroad tracks, backwater from downstream systems, and the low ground surface elevation in the intersection. Flow from upstream of the intersection was diverted down along the railroad track ROW in an effort to alleviate flooding at the intersection and to relieve high backwater upstream of Braddock Road and West Street. The 48-inch circular pipe diversion is about 2,400 linear feet (LF). It begins downstream of the intersection (003458SMH) and discharges to the eastern barrel of Hooffs Culvert just upstream of the intersection of Commonwealth Avenue and King Street (000946ND), as shown on Figure 3-5. The capital cost for this solution is estimated to be approximately $1.4 million. It should be recognized that the proposed solution utilizes the easement along the railroad, which may not be feasible, or may significantly increase the capital cost. Model results are presented at the end of this section.

FIGURE 3-5
Braddock Road and West Street Major Conveyance Solution
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run





3.3 Modeling Results

3.3.1 Major Storage Results

The two major storage projects were set up in a single xpswmm model run. The model results are presented in Figure 3-6. By comparing flooding to existing conditions shown in Figure 2-1, the results for the Hooffs Culvert storage solution show that conditions along the single barrel of Hooffs Culvert are improved, but there is still substantial flooding along portions of the culvert and at the location where Timber Branch transitions into the culvert. Aside from the poor performance in the model, this storage option was not considered a feasible alternative for Hooffs Culvert due to high cost and constructability implications.

The storage solution upstream of Braddock Road and West Street relieved flooding in the low point of the intersection, but pipes upstream of the intersection still experience a significant amount of flooding. These results again indicate that the pipes along West Street and Wythe Street may be undersized.

3.3.2 Major Conveyance Results

The major conveyance projects were set up in a single xpswmm model run. The model results are presented in Figure 3-7. The diversion of Timber Branch down Russell Road relieved much of the flooding and backwater in the single barrel of Hooffs Culvert. The model results of this solution indicate that removing the Timber Branch inflows from the single barrel of Hooffs Culvert significantly improves capacity within Subwatersheds 3 and 4. The culvert does not experience flooding between Spring Street and Bellefonte, and conditions in branches connected to the culvert are also improved.

The conveyance results for Braddock Road and West Street show that flooding at the intersection is relieved; however, flooding still occurs upstream of the intersection. Again, this points to 010636STMP as a significant contributor to the flooding in the intersection. Because this pipe has very limited cover and is undersized, the ground surface is quickly flooded during wet-weather conditions. Improvements to these local pipe segments are included as Problem Area 3 in the conveyance solutions portion of Solutions Identification section.

3.4 Major Capacity Project Conclusions

Preliminary capital cost estimates are provided for each of the major capacity projects discussed above. Preliminary cost estimates were developed for the alternatives using approaches summarized in the Alternatives Analysis and Prioritization section of this TM.

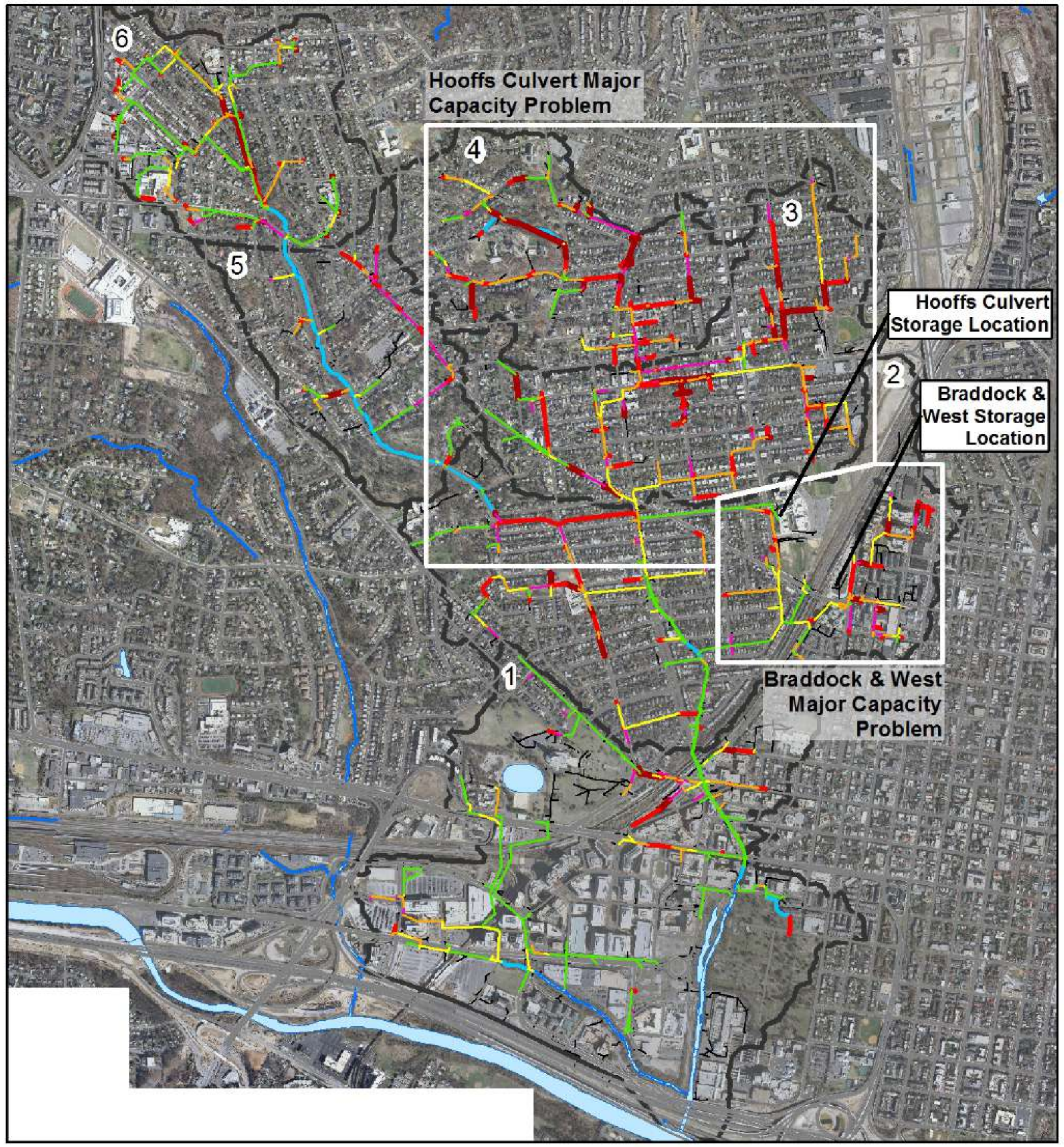
Table 3-1 summarizes the results and capital costs developed for each of the major capacity projects. The Hooffs Culvert storage solution did not perform as well as the conveyance solution with respect to flood reduction. The capital costs for both projects are similar, but due to the constructability and operations and maintenance implications of building a 13 MG storage facility, the storage alternative was not considered feasible, and the conveyance project was selected for the next stage of modeling. Both solutions at Braddock Road and West Street provided only moderate flood reduction. While the storage solution performed better in the model, the conveyance solution did a better job of eliminating backwater and downstream capacity limitations. In addition to constructability concerns related to the storage facility, the capital cost associated with the conveyance project is lower than the storage solution. For these reasons, the conveyance project was selected for the next stage of modeling.

TABLE 3-1
Major Capacity Project Summary
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

	LF of Flooded Pipe in Project Drainage Area[a]		% of Total Length Flooded in Drainage Area[a]		Capital Cost Estimate[b]
	Existing	Solution	Existing	Solution	
Hooffs Culvert Storage	36,698	32,299	46.3	40.6	$18.5M
Hooffs Culvert Conveyance	36,698	26,413	46.3	34.0	$13.6M
Braddock and West Storage	3,391	3,084	52.0	47.3	$2.8
Braddock and West Conveyance	3,391	3,309	52.0	51.2	$1.4M

[a] Drainage area includes all pipes upstream of the proposed project.
[b] Preliminary cost estimates were developed using approaches summarized in the Alternatives Analysis and Prioritization section of this TM.

FIGURE 3-6
Major Storage Solution Model Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



Legend

Model Results Sufficient Capacity; Surcharged; Insufficient Freeboard

Volume (cu. ft.) 0.01 - 1,000; 1,000 - 10,000; 10,000 - 93,100; Not Analyzed (Private, disconnected, upstream of runoff input)

Water Bodies; Modeled Streams; City of Alexandria Streams; Subwatersheds

Note: Subwatershed number provided in upper corner of each subwatershed

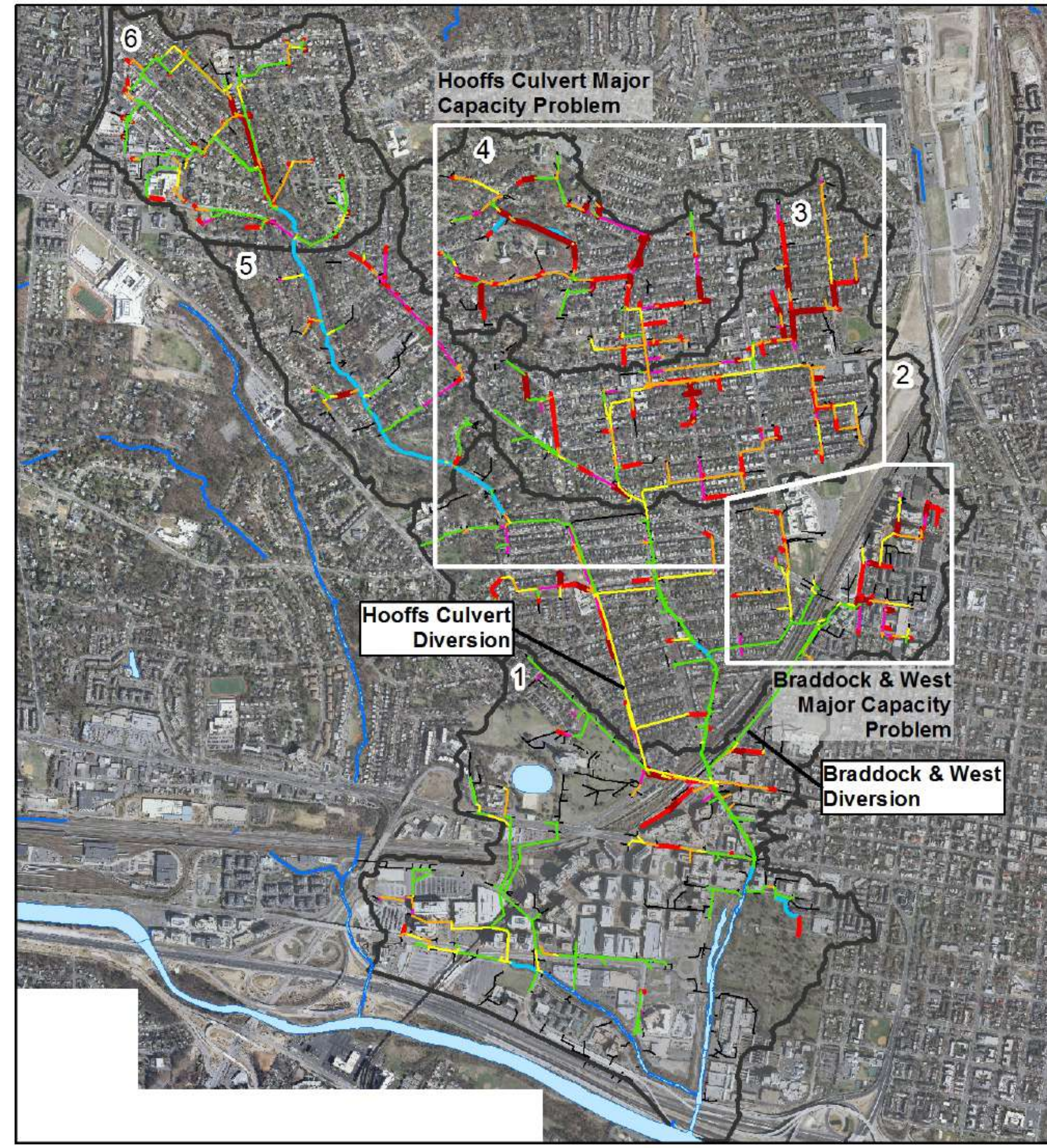
Major Storage Solution Model Results
Existing IDF, Existing Boundary Conditions
Task 4 Problem and Solution Identification and Prioritization for Hooffs Run

0 750 1,500 3,000
Feet

N

CH2MHILL

FIGURE 3-7
Major Conveyance Solution Model Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



Legend

Model Results Sufficient Capacity; Surcharged; Insufficient Freeboard

Volume (cu. ft.) 0.01 - 1,000; 1,000 - 10,000; 10,000 - 87,200; Not Analyzed (Private, disconnected, upstream of runoff input)

Water Bodies; Modeled Streams; City of Alexandria Streams; Subwatersheds

Note: Subwatershed number provided in upper corner of each subwatershed

Major Conveyance Solution Model Results
Existing IDF, Existing Boundary Conditions
Task 4 Problem and Solution Identification and Prioritization for Hooffs Run

0 750 1,500 3,000
Feet

N

CH2MHILL

SECTION 4
Problem Identification

The purpose of the problem identification task was to assign a score to structures in the stormwater drainage network so that high-priority problem areas could be identified. Solution alternatives were developed for high-priority problem areas in the Hooffs Run Watershed. Junctions were scored for each of the problem area evaluation criteria. Table 4-1 shows the distribution of scores across the 2,872 stormwater junctions in Hooffs Run. These results were generated using the Task 2 existing condition model (existing IDF, existing boundary conditions) with the model refinements, baseline projects and major conveyance projects described in the Approach section of this TM.

TABLE 4-1
Hooffs Run Problem ID Scores
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

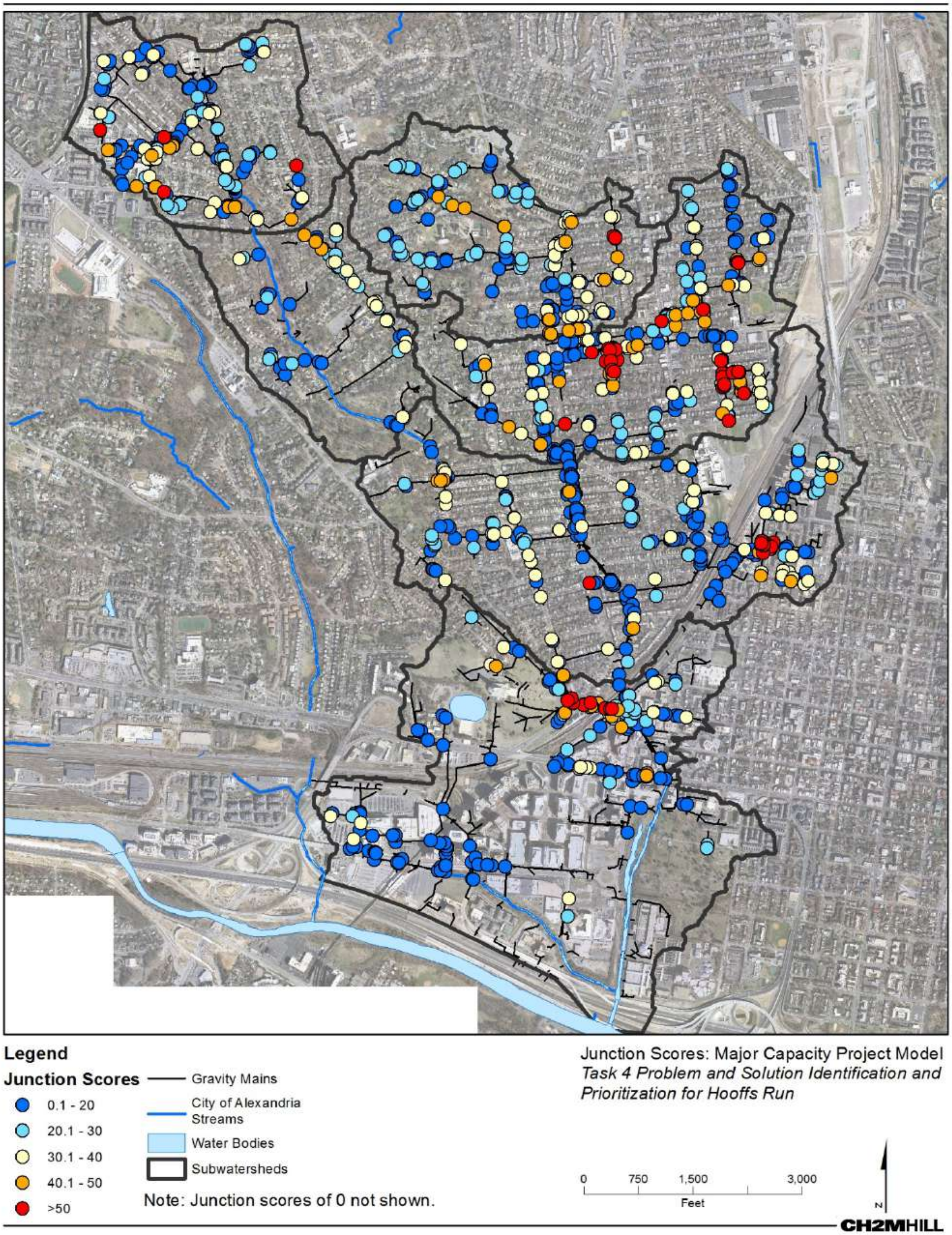
Problem ID Score	Count of Junctions	% of Total
0	1,772	61.7
0.1 – 20	539	18.8
20.1 – 30	228	7.9
30.1– 40	192	6.7
40.1 – 50	85	3.0
>50	56	1.9
Total	**2,872**	**100**

A map of the junction scores is provided on Figure 4-1.

After scoring individual junctions, high-priority problem areas were identified as groupings of hydraulically connected junctions and pipes in proximity to one another. Initial junction scores and high-priority problem area delineations were based on the existing conditions model results; however, scores and high-priority problem area delineations were updated where necessary using model results that included the baseline conditions updates and major capacity projects.

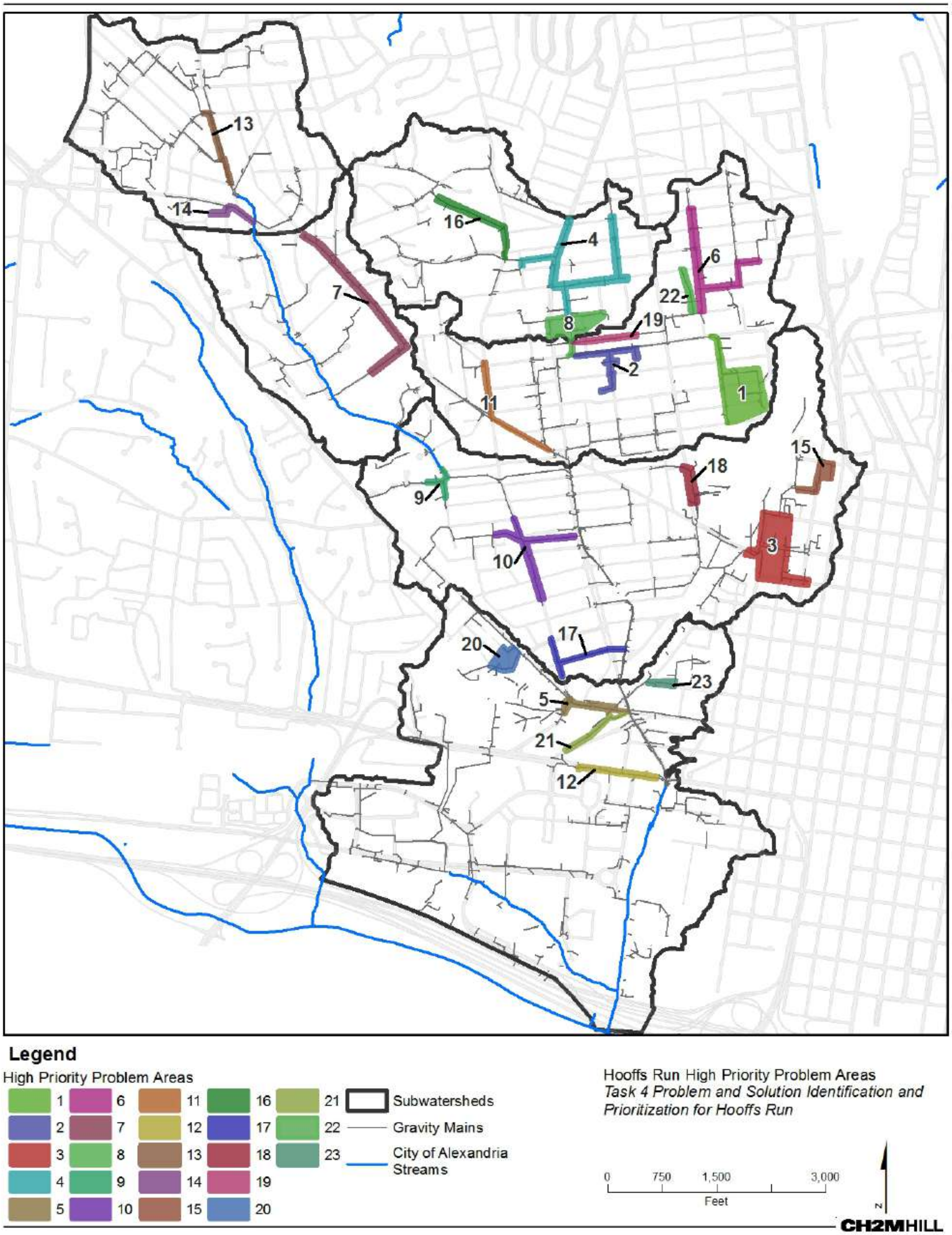
After reviewing the results and updating the junction scoring with the results of the model, including the major capacity projects, a total of 23 high-priority problem areas remained. These 23 areas are shown on Figure 4-2.

FIGURE 4-1
Hooffs Run Problem Identification Score Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



np

FIGURE 4-2
Location of Hooffs Run High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



SECTION 5

Solution Identification

A suite of solutions, including conveyance, conventional SWM (modeled as storage), and green infrastructure projects, was developed for each problem area. The solution identification process resulted in 111 unique projects for the 23 high-priority problem areas in the Hooffs Run Watershed. The following section describes the specific solutions developed for each problem area by project type, as well as the model results.

5.1 Conveyance Solutions

A conveyance solution was developed for each of the high-priority problem areas. The goal of the conveyance solutions was to remove hydraulic limitations in the drainage network by increasing the capacity of the pipes in high-priority problem areas. Since this was a high-level conceptual exercise rather than a design exercise, the pipe alignment and roughness were left unchanged, and capacity was increased solely by increasing the pipe size. In most cases, pipe shape was not altered except where sufficient capacity could not be achieved due to limited cover or where the existing pipe was a special shape, such as horizontal elliptical pipes. Where there was limited cover, circular pipes were changed to box culverts so that capacity could be increased without daylighting. Special pipe shapes were converted to equivalent-diameter circular pipes to simplify the model and calculations.

The conveyance capacity required was estimated using xpswmm. A hydraulic model was used to approximate the unconstrained peak flow in each pipe segment by upsizing pipes to 0.1 inch bgs to maximize diameter without daylighting the pipe, and by increasing the number of barrels by a factor of 2 across the board. The resulting unconstrained peak flow and Manning's equation were used to back-calculate the diameter required for the pipe to flow less than 80 percent full.

In the high-priority problem areas, the required diameter was compared to the existing diameter. Pipes that were smaller than the required pipe size calculated using the unconstrained peak flow were upsized and included in the conveyance project. Pipes that had sufficient capacity under existing conditions were left unchanged. Pipe size was not optimized during this exercise, and runs of pipes were not consistently sized. A summary of the length of pipe and range of pipe sizes included in each conveyance solution is included in Table 5-1. A table documenting the existing and proposed diameter of each pipe segment is provided in Appendix B.

TABLE 5-1
Summary of Conveyance Projects
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Problem Area ID	Project ID	Replacement Pipe Size Range and Project Description	Length (LF)
1	CONV-1	24-72 Inch Replacement Sewer Pipe Relief	3,203
2	CONV-2	18-42 Inch Replacement Sewer Pipe Relief	1,289
3	CONV-3	30-72 Inch Replacement Sewer Pipe Relief	1,753
4	CONV-4	30-96 Inch Replacement Sewer Pipe Relief	3,695
5	CONV-5	24-66 Inch Replacement Sewer Pipe Relief	1,005
6	CONV-6	30-78 Inch Replacement Sewer Pipe Relief	2,607
7	CONV-7	24-54 Inch Replacement Sewer Pipe Relief	2,696
8	CONV-8	24-94 Inch Replacement Sewer Pipe Relief	1,646
9	CONV-9	24-48 Inch Replacement Sewer Pipe Relief	394
10	CONV-10	24-54 Inch Replacement Sewer Pipe Relief	1,609
11	CONV-11	30-54 Inch Replacement Sewer Pipe Relief	1,533

TABLE 5-1
Summary of Conveyance Projects
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Problem Area ID	Project ID	Replacement Pipe Size Range and Project Description	Length (LF)
12	CONV-12	30-40 Inch Replacement Sewer Pipe Relief	598
13	CONV-13	30-78 Inch Replacement Sewer Pipe Relief	1,142
14	CONV-14	24-30 Inch Replacement Sewer Pipe Relief	404
15	CONV-15	24-36 Inch Replacement Sewer Pipe Relief	842
16	CONV-16	30-36 Inch Replacement Sewer Pipe Relief	1,470
17	CONV-17	24-42 Inch Replacement Sewer Pipe Relief	954
18	CONV-18	24-36 Inch Replacement Sewer Pipe Relief	551
19	CONV-19	77-77 Inch Replacement Sewer Pipe Relief	728
20	CONV-20	18-24 Inch Replacement Sewer Pipe Relief	689
21	CONV-21	30-36 Inch Replacement Sewer Pipe Relief	618
22	CONV-22	18-30 Inch Replacement Sewer Pipe Relief	336
23	CONV-23	36-48 Inch Replacement Sewer Pipe Relief	393

A map of the major capacity model results is provided on Figure 5-1 for reference, and a map of the conveyance solution model results is provided on Figure 5-2. A summary of the results is provided in Table 5-2.

FIGURE 5-1
Major Capacity Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

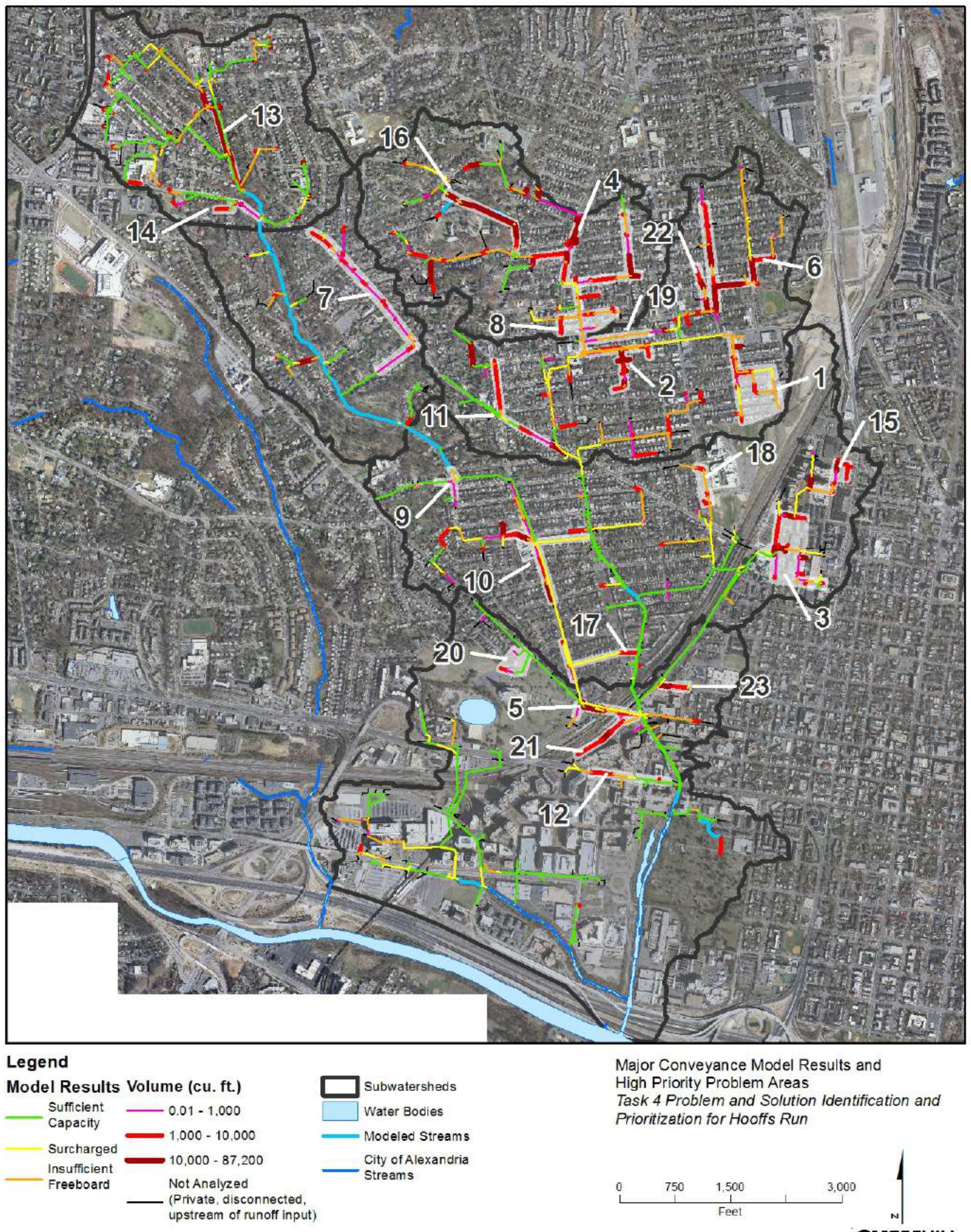
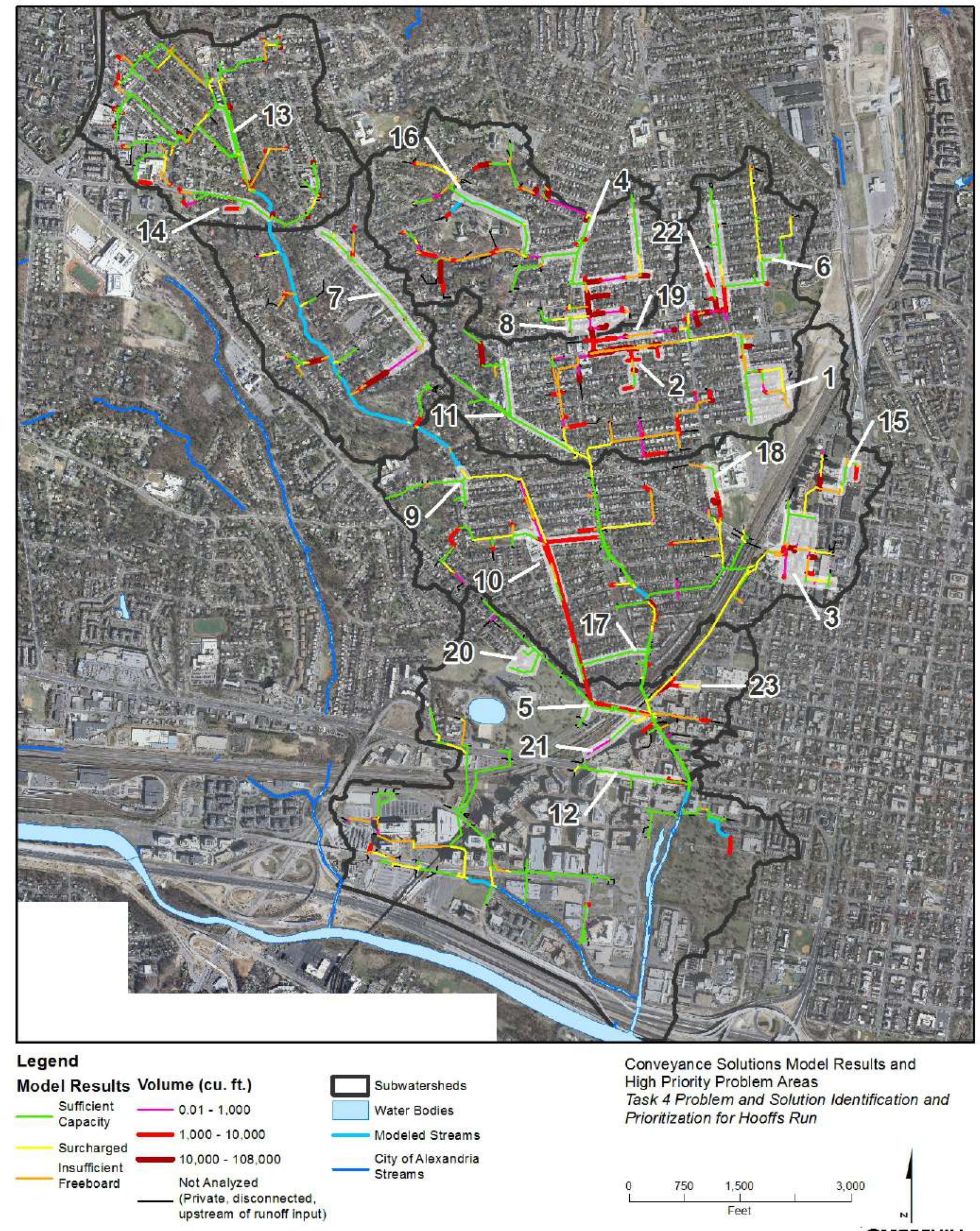


FIGURE 5-2
Conveyance Solutions Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



The conveyance solutions resolve some localized problems within the high-priority problem areas; however, much of the peak flow and volume is passed downstream creating new flooding and capacity limitations. Table 5-2 summarizes the model results for the major capacity projects, which is the starting point for the conveyance solution model and the conveyance solutions. Side-by-side comparison shows that overall flooding is eliminated in about 7 percent of the system by length. Though the total volume flooded is only reduced by about 25 percent, the duration of surcharge and flooding are both reduced by more than 50 percent, indicating the severity of flooding is substantially reduced.

TABLE 5-2
Summary of Major Capacity and Conveyance Model Results in Hooffs Run
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

	Major Capacity Results				Conveyance Solutions Results			
	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]
Sufficient Capacity	53,672	37	-	-	70,062	48	-	-
Surcharged[a]	23,050	16	1,401	-	22,491	15	687	-
Insufficient Freeboard	30,436	21	-	-	24,606	17	-	-
Flooded	38,368	26	624	2,914,887	28,367	19	281	2,330,684

Notes:
Results presented for pipe segments are based on capacity at upstream end of pipe.
[a] Duration of surcharged flow includes time during which conduits have insufficient freeboard or are flooded at upstream end only.
[b] Flooded volume includes volume flooded at upstream end of the conduit.

A summary of the modeling results within the high-priority problem areas is provided in Table 5-3. Not including Problem Areas 8, 19, and 22, where flood volume was increased, the average flood volume was reduced by 73 percent within the high-priority problem areas. The disadvantage of conveyance solutions is that, while increasing pipe capacity reduces flooding in the problem area, it increases peak flows, which can create or increase flooding downstream. Peak flow was increased for all 23 high-priority problem areas, though this increase was much higher in some problem areas, ranging from a 6 percent increase in Problem Area 9 and a 357 percent increase in Problem Area 7.

TABLE 5-3
Conveyance Solution Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

	Flood Volume (MG)			Peak Flow at Downstream End of Problem Area (cfs)		
Problem Area ID	Major Conveyance Model Results	Conveyance Solution Model Results	Percent Reduction[a]	Major Conveyance Model Results	Conveyance Solution Model Results	Percent Increase
1	0.355	0.064	82	56	80	42
2	1.022	0.833	18	10	33	221
3	1.248	0.274	78	57	131	129
4	2.909	2.216	24	143	409	186
5	1.283	-	100	51	194	280
6	2.250	1.141	49	47	99	112
7	0.290	0.009	97	21	95	357
8	0.133	2.325	-1,647	56	226	300

TABLE 5-3
Conveyance Solution Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

	Flood Volume (MG)			Peak Flow at Downstream End of Problem Area (cfs)		
Problem Area ID	Major Conveyance Model Results	Conveyance Solution Model Results	Percent Reduction[a]	Major Conveyance Model Results	Conveyance Solution Model Results	Percent Increase
9	0.003	-	100	769	814	6
10	0.394	0.124	68	103	126	22
11	0.377	-	100	75	137	83
12	0.142	0.073	48	40	55	38
13	0.912	0.016	98	152	280	85
14	0.182	0.018	90	26	40	54
15	0.415	0.013	97	15	55	273
16	0.620	-	100	57	112	96
17	0.035	0.006	83	40	50	26
18	0.195	0.297	-52	36	44	23
19	0.001	0.465	-82,432	77	154	101
20	0.037	-	100	61	83	37
21	0.126	0.002	98	22	42	90
22	0.362	0.431	-19	8	31	277
23	0.421	0.086	80	24	86	261
		Average	**69%[b]**			**135%**

Note:
[a] Negative value in Percent Reduction column indicates an increase in flood volume.
[b] Problem areas 8 and 19 were excluded from the average as outliers due to extreme downstream impacts.

The approach of sizing the conveyance projects based on the unconstrained peak flow allowed all conveyance projects to be run in a single iteration. Since stormwater gravity main diameters were increased to convey the largest potential peak flow, the impact of increasing capacity upstream was incorporated into the sizing of any downstream conveyance solutions. However, evaluating all of the conveyance projects in a single model run has several limitations. Because the problem areas are interconnected, modeling all solutions in a single run does not allow each solution to be viewed independently. Several problem areas are in proximity to one another; therefore, increasing the capacity at one location impacts the hydraulics in nearby problem areas, either by adding additional flow downstream or potentially increasing backwater for adjacent problem areas.

For example, Problem Areas 8 and 19, which are located at the upstream end of Hooffs Culvert near the intersection of Commonwealth Avenue and Monroe Street, are downstream of Problem Areas 4, 6, 16, and 22 and adjacent to Problem Areas 1 and 2. Because Problem Areas 8 and 19 are directly downstream of other problem areas, adding conveyance solutions to the model for all problems at once causes the peak flow and volume passing through Problem Areas 8 and 19 to be greater than if these two areas were modeled separately, potentially decreasing the modeled performance of the solutions. This is clear when reviewing the results presented in Table 5-3; the flood volume increased from 0.13 MG to 2.33 MG in Problem Area 8 and from 0.001 MG to 0.46 MG in Problem Area 19.

Additionally, modeling all of the conveyance projects at once causes substantial flooding downstream of these closely located projects. The combined effect of modeling all of these conveyance projects at once is that a very large peak flow and volume are able to pass through areas that previously had capacity limitations, which only causes a capacity limitation downstream. The map presented on Figure 5-2 shows the conveyance solution results. Comparison of Figures 5-1 and 5-2 show that there is marked increase in flooding in the central portion of the system downstream of Problem Areas 8 and 19.

5.2 Conventional Stormwater Management Solutions

Conventional SWM solutions considered in this study include detention facilities and ordinance changes. Due to the challenges of translating ordinance changes into hydrologic and hydraulic parameters, only detention solutions were modeled in xpswmm. Ordinance changes are discussed later in this section.

5.2.1 Storage Solutions

The goal of storage solutions was to add storage to the stormwater drainage network to decrease peak flow and volume during the modeled rainfall event. Due to the urban nature of the study area, it was assumed that to provide a sufficient storage volume, detention facilities would have to be below grade vaults. Several constraints guided the siting of potential storage solutions, including:

- Depth of storage facility should not exceed 10 feet to minimize excavation costs
- Storage will be dewatered by gravity to a manhole less than 1,000 feet downstream to eliminate pumping costs
- Minimum storage depth should be 3 feet, measured from the storage inlet to the storage outlet
- Only surcharged flow will be sent to storage

The first step in developing storage solutions was to identify open space that may be available for subsurface storage vaults with preference for City-owned property. This primarily included parking lots, green space (for example, parks, school yards, playing fields, church yards), and grassed medians or boulevards. These opportunities were identified using aerial imagery and were deemed feasible using drainage network data (gravity main locations and inverts) and topographic data. Storage areas meeting the constraints described above were identified for 19 of the high-priority problem areas; no storage opportunities were identified for Problem Areas 9, 13, 14, or 20; multiple storage areas were identified in Problem Areas 2, 3, 4, 6, and 8. A map of these locations is provided on Figure 5-3, and Table 5-4 summarizes the storage depth, area, and volume. More detailed maps of the storage solution locations are provided in Appendix C.

FIGURE 5-3
Storage Solution Locations and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

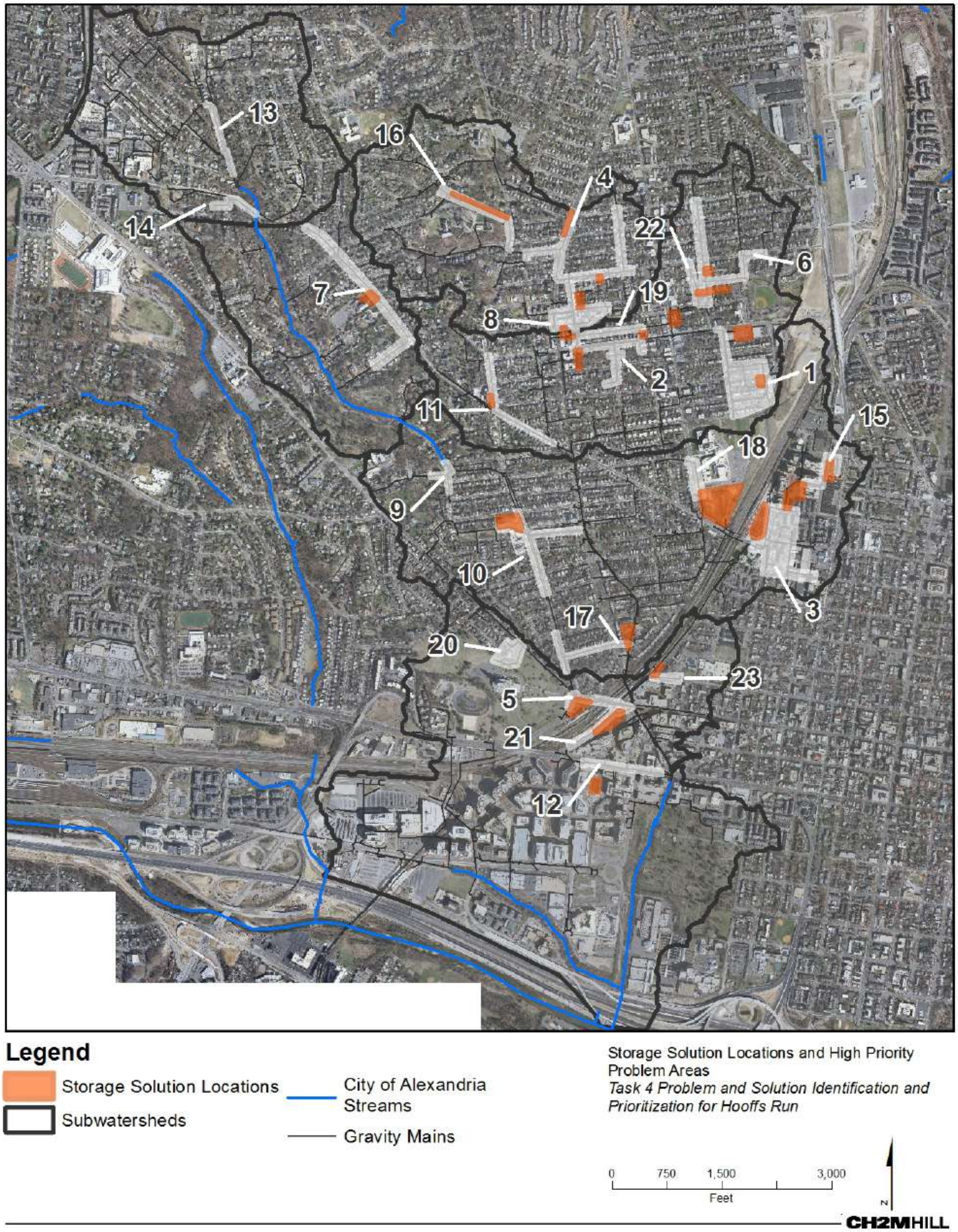


TABLE 5-4
Storage Solutions Summary
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Problem Area ID	Storage ID	Max Depth (ft)	Total Storage Area Available (ft^2)	Total Volume Available (ft^3)	Total Volume Required (ft^3)
1	STOR_01	4.27	7,537	32,177	21,705
2	STOR_02	9.83	30,812	302,881	21,143
2	STOR_06	5.71	3,528	20,147	15,586
2	STOR_07	7.39	13,492	99,707	46,081
3	STOR_03	10.0	51,875	518,745	166,316
3	STOR_17	10.0	45,140	451,404	119
4	STOR_04	6.34	3,035	19,228	18,698
4	STOR_05	9.35	4,984	46,605	46,605
5	STOR_12	10.0	32,172	321,719	165,973
6	STOR_09	9.22	7,599	70,064	54,529
6	STOR_10	9.17	10,792	98,966	98,966
7	STOR_13	5.01	17,471	87,531	66,188
8	STOR_14	8.62	10,913	94,029	5,869
8	STOR_15	4.00	11,819	47,277	0
10	STOR_16	10.0	46,347	463,473	68,876
11	STOR_21	9.20	4,396	40,432	21,191
12	STOR_18	10.0	17,872	178,721	31,678
15	STOR_08	5.37	14,161	76,017	56,036
16	STOR_25	7.00	5,766	40,363	25,002
17	STOR_19	6.94	23,542	163,310	25,715
18	STOR_20	10.0	184,481	1,844,814	20,711
19	STOR_11	8.83	18,410	162,512	4,879
21	STOR_23	10.0	37,883	378,828	28,595
22	STOR_22	4.38	3,554	15,572	15,572
23	STOR_24	6.94	5,822	40,405	38,849

Note: No storage opportunities were identified for problem areas 9, 13, 14, or 20

A map of the results of the storage solution model run is provided on Figure 5-4, and a summary of the results is provided in Table 5-5.

FIGURE 5-4
Storage Solution Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

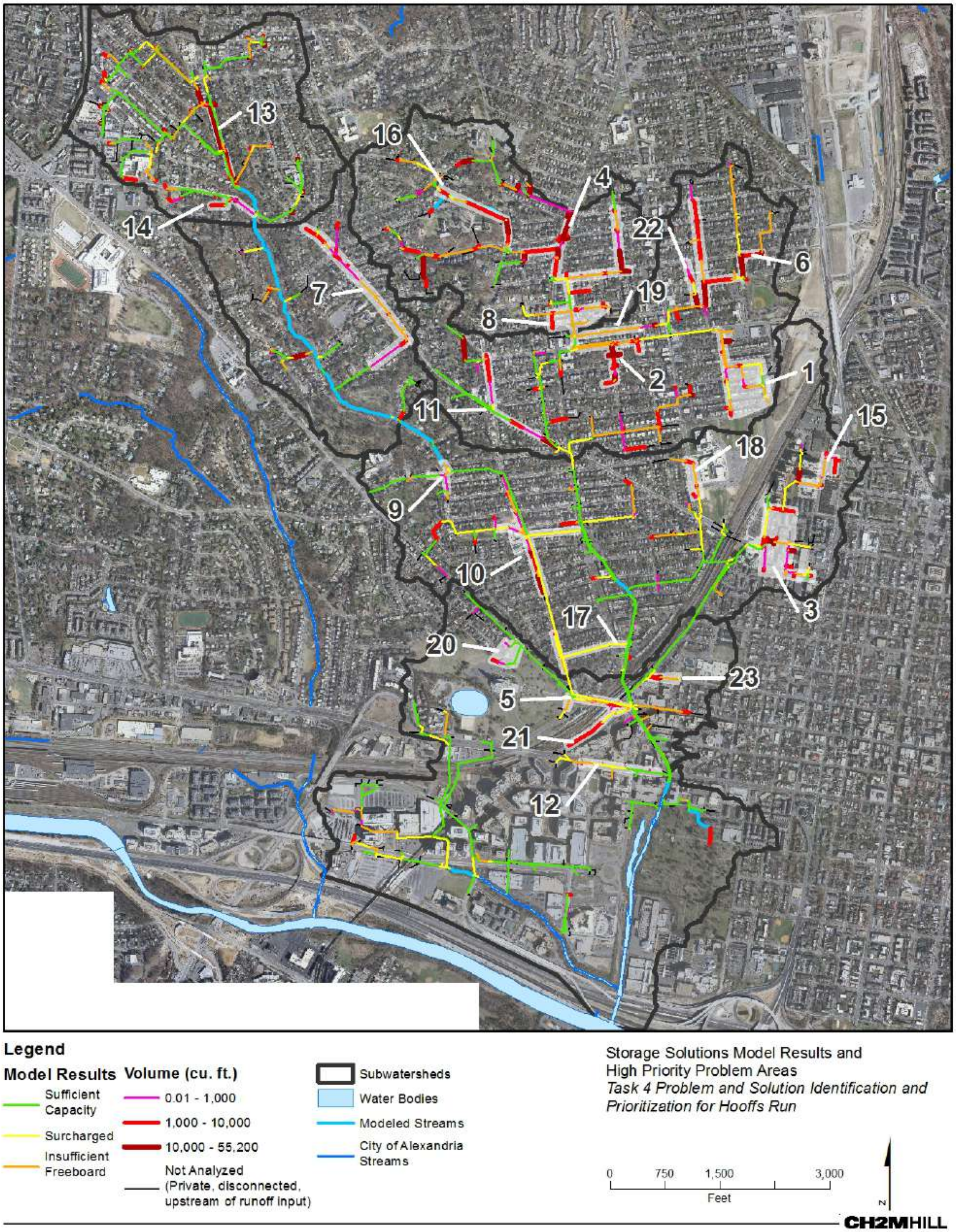


TABLE 5-5
Summary of Major Capacity and Storage Model Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

	Major Capacity Results				Storage Solutions Results			
	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft³)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft³)[b]
Sufficient Capacity	53,672	37	-	-	56,565	39	-	-
Surcharged[a]	23,050	16	1,401	-	25,233	17	1,189	-
Insufficient Freeboard	30,436	21	-	-	32,093	22	-	-
Flooded	38,368	26	624	2,914,887	31,635	22	469	2,061,526

Notes:
Results presented for pipe segments are based on capacity at upstream end of pipe.
[a] Duration of surcharged flow includes time during which conduits have insufficient freeboard or are flooded at upstream end only.
[b] Flooded volume includes volume flooded at upstream end of the conduit.

Overall, the storage solutions decrease the total volume of flooding in the watershed by almost 30 percent, and the duration of flooding is decreased by about 25 percent. Flooding is eliminated in about 4 percent of the system, by length, but this does not translate to a 4 percent increase in pipes with sufficient capacity. Instead, there is a slight increase in the length of pipe that is surcharged, has insufficient freeboard or has sufficient capacity. The total duration of surcharge is reduced by about 15 percent. However, these model results are for the system at large. A summary of the modeling results within the high-priority problem areas is provided in Table 5-6. On average, the flood volume was reduced by 54 percent within the high-priority problem areas, and the peak flow was reduced by almost 5 percent.

TABLE 5-6
Storage Solution Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

	Flood Volume (MG)			Peak Flow at Downstream End of Problem Area (cfs)		
Problem Area ID	Major Conveyance Model Results	Storage Solution Model Results	Percent Reduction	Major Conveyance Model Results	Storage Solution Model Results	Percent Reduction[a]
1	0.355	0.106	70	56	54	3
2	1.022	0.969	5	10	11	-9
3	1.248	0.681	45	57	56	3
4	2.909	2.441	16	143	141	2
5	1.283	0.081	94	51	50	1
6	2.250	1.024	54	47	42	10
7	0.290	0.213	27	21	21	0
8	0.133	0.091	31	198	196	1
10	0.394	0.196	50	103	103	0
11	0.377	0.263	30	75	74	2
12	0.142	0.014	90	40	39	2
15	0.415	0.074	82	15	15	1
16	0.620	0.379	39	57	57	0
17	0.035	0.012	67	40	29	26

TABLE 5-6
Storage Solution Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

	Flood Volume (MG)			Peak Flow at Downstream End of Problem Area (cfs)		
Problem Area ID	Major Conveyance Model Results	Storage Solution Model Results	Percent Reduction	Major Conveyance Model Results	Storage Solution Model Results	Percent Reduction[a]
18	0.195	0.067	66	36	33	8
19	0.001	0.000	99	77	78	-2
21	0.126	0.076	40	22	17	23
22	0.362	0.195	46	8	7	12
23	0.421	0.132	69	24	22	7
		Average	**54**			**5**

Note:
[a] Negative value in Percent Reduction column indicates an increase in flood volume.
No storage opportunities were identified for Problem Area 9, 13, 14, or 20.

Evaluating all of the storage solutions in a single model is not limited by increases in downstream impacts as the conveyance solutions are. Instead, due to the increased storage capacity at upstream problem areas, the full peak flow may not reach downstream problem areas. In this case, the performance of a problem area may appear to be more favorable than if each problem area were modeled separately.

5.2.2 Stormwater Ordinance Changes

The intent of the current study was to identify existing capacity limitations in the system and potential solutions, however future land use changes were not considered. The City stormwater ordinances focus on development and redevelopment projects, therefore would not affect the results of this study. However, the City is in the process of modifying City Ordinance Section XIII to comply with new state requirements, and the more stringent requirements included in the ordinance will create an avenue for implementation of the projects that are identified in this report.

The revised ordinance provides greater protection for natural intermittent channels. If the adjacent parcels are developed or redeveloped, then a reduction in peak flow rates will likely be required, and this study could be used to identify potential projects that could be implemented by the developer to reduce peak flows.

The state law and the ordinance definition of adequate outfall have changed; 13-109(F)2.b provides criteria for the case when the existing stormwater conveyance system currently experiences localized flooding during the 10-year 24-hour storm event. The revised ordinance will require additional onsite detention or downstream improvements such that existing problems are not exacerbated. This study is anticipated to be one of the primary reference points for identifying which locations in the City fall under this provision.

The Runoff Reduction Method calculation used in the new ordinance will likely make it more difficult to achieve compliance for a highly impervious site. As a result, there may be more need to use offsite compliance options, including the City's Water Quality Improvement Fund to achieve plan approval, which could provide funding for the projects recommended in this study.

5.3 Green Infrastructure Solutions

The goal of green infrastructure solutions was to reduce the peak runoff rate and runoff volume directed to the storm drainage system by converting impervious surfaces to pervious surfaces. This is accomplished in the field by redirecting runoff from impervious surfaces to green infrastructure facilities that detain and infiltrate runoff during rainfall events. Three levels of green infrastructure—low, medium, and high—were evaluated in this analysis. In the model, green infrastructure was evaluated by reducing the impervious cover in model subcatchments by 10 percent, 30 percent, and 50 percent to represent the low, medium, and high levels of implementation, respectively.

Several green infrastructure technologies were considered feasible within the City of Alexandria including:

- **Bioretention/ Planters** – planted depression or constructed box with vegetation that typically receives runoff from roadways or rooftop; includes vegetation and soil media over an underdrain and filtration fabric; The City does not typically encourage infiltration, therefore rain gardens, which typically do not have an underdrain, are not encouraged.
- **Cisterns** – a tank for storing water, typically connected to a roof drain, which can be either above or below ground; water from a cistern is typically reused or slowly infiltrated into the soil rather than discharged to a storm sewer
- **Green/Blue Roofs** - a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane (green roof) or a roof that is capable of storing and then slowly releasing rainwater (blue roof)
- **Porous Pavement** - paving surfaces designed to allow stormwater infiltration; may or may not include underground storage component
- **Surface Storage** – retrofit of inlets and catch basins to include flow regulators on streets with standard curb and gutter system so that stormwater can be stored within the roadway and slowly released back into the storm sewer system
- **Amended Soils** – altering soils to improve water retention, permeability, infiltration, drainage, aeration, and/or structure

These technologies were grouped into green infrastructure programs based on the land uses where they could be applied: A program combines a set of technologies into an implementation strategy for different types of sites and land use categories. Programs being considered are described below.

- **Green Streets/Alleys** – includes bioretention/planters and porous pavement combined along the public ROW between buildings and roadways; can include parking lane and curb cuts
- **Green Roofs** – includes green/blue roofs, sometimes in combination with cisterns
- **Green Schools** – use of school properties to implement one-to-many green infrastructure management strategies, including bioretention/planters, cisterns, green/blue roofs, and porous pavement
- **Green Parking** – bioretention/planters and porous pavement in parking lots
- **Green Buildings** – use of bioretention/planters, cisterns, and/or downspout disconnection on public or private buildings
- **Blue Streets** – short term surface storage on streets with relatively flat slopes and standard curb and gutter systems
- **Open Spaces** – use of open spaces to store and/or infiltrate stormwater with the use of a combination of detention, amended soils, bioretention/planters, and/or porous pavement; may also include the use of stream daylighting where appropriate

Six green infrastructure concepts were developed for the Hooffs Run Watershed. These concepts, which are described in greater detail in Appendix D, demonstrate the applicability of green infrastructure technologies in the City of Alexandria.

A drainage area for each high-priority area was identified using the model's hydrologic subcatchments. Because the drainage area includes all model subcatchments upstream of the problem area, where there are problem areas upstream of one another, drainage areas overlap. A map of these drainage areas and problem area locations is provided on Figure 5-5, and Table 5-7 summarizes the drainage area, existing impervious area, and impervious area for each level of green infrastructure implementation.

FIGURE 5-5
Green Infrastructure Drainage Areas and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

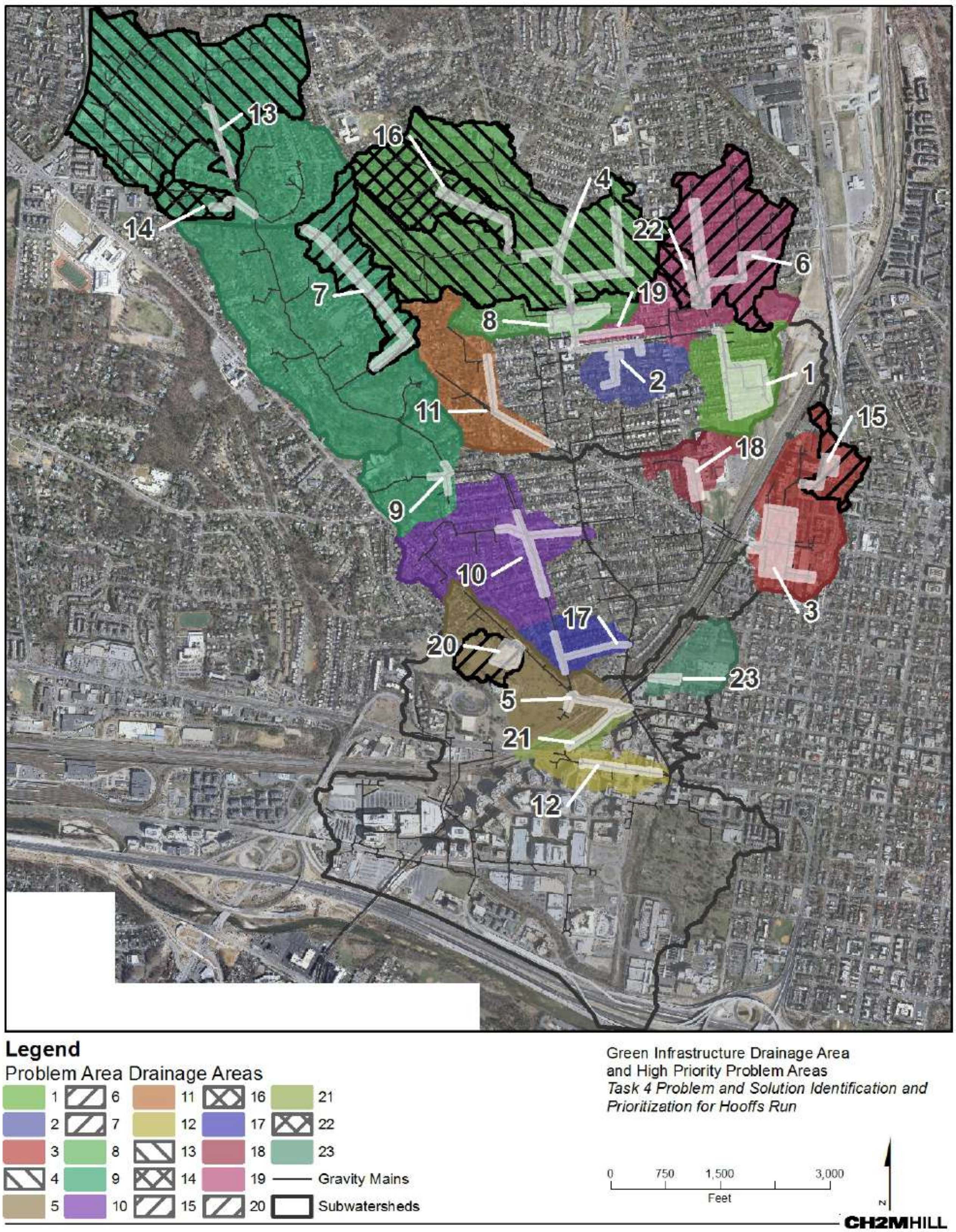


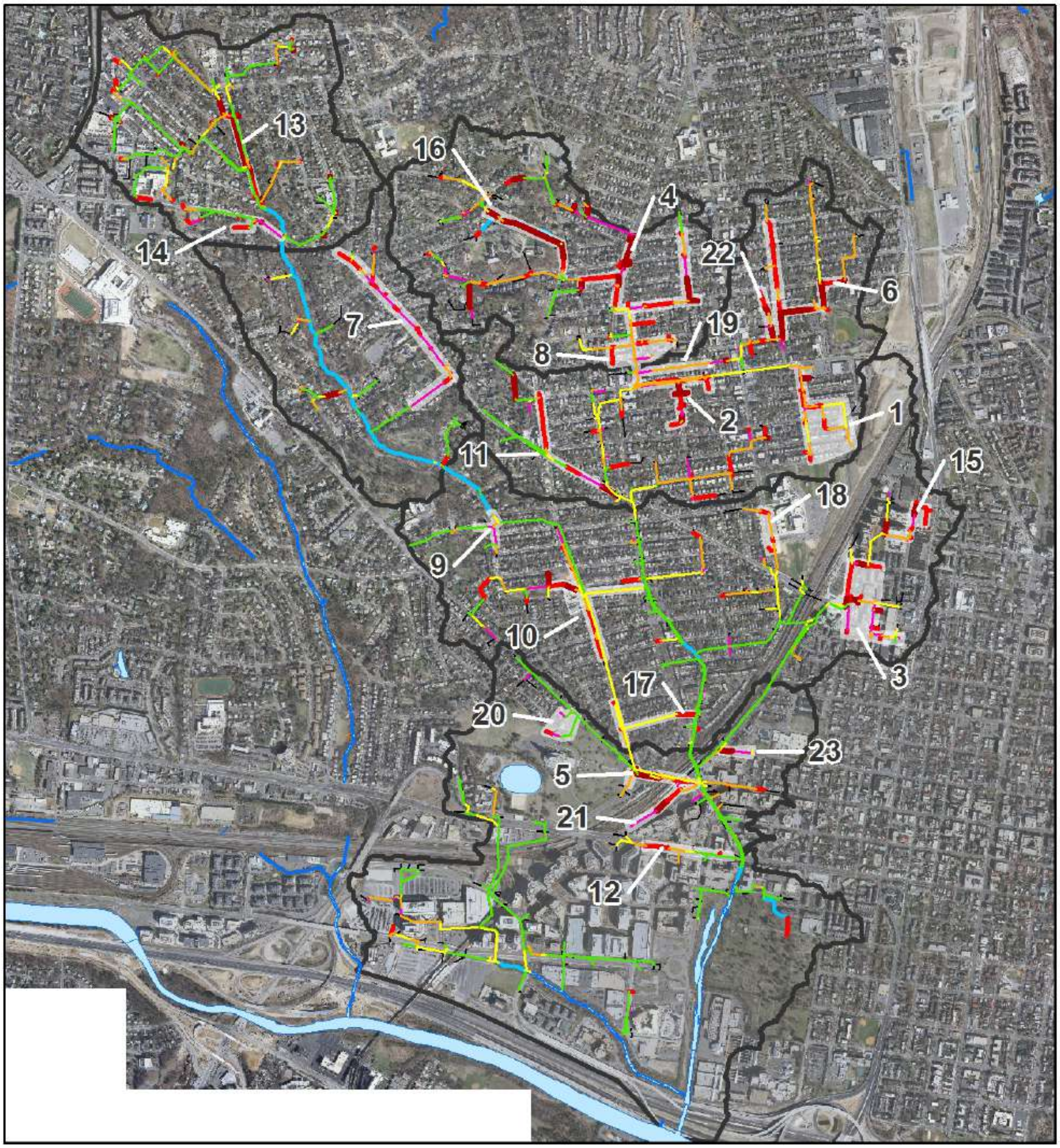
TABLE 5-7
Green Infrastructure Solutions Summary
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Problem Area ID	Drainage Area (acres)	Existing Impervious Area (acres)	Green Infrastructure Solution Impervious Area (acres)		
			Low Implementation	Medium Implementation	High Implementation
1	32.6	14.8	13.4	10.4	7.4
2	19.6	7.7	7.0	5.4	3.9
3	56.2	40.4	36.4	28.3	20.2
4	173.9	65.5	58.9	45.8	32.7
5	49.8	17.2	15.5	12.0	8.6
6	60.8	25.0	22.5	17.5	12.5
7	32.9	12.1	10.9	8.4	6.0
8	196.2	74.9	67.4	52.5	37.5
10	370.0	132.0	118.8	92.4	66.0
11	72.2	28.9	26.0	20.2	14.5
12	43.2	13.3	12.0	9.3	6.7
15	15.3	12.9	11.6	9.1	6.5
16	119.6	56.8	51.2	39.8	28.4
17	12.3	4.7	4.2	3.3	2.3
18	12.2	9.8	8.8	6.8	4.9
19	36.1	11.9	10.7	8.3	6.0
21	17.0	8.0	7.2	5.6	4.0
22	15.6	7.6	6.9	5.3	3.8
23	88.9	39.7	35.8	27.8	19.9

Maps of the results of the low, medium, and high green infrastructure solutions are provided on Figures 5-6 through 5-18, and a summary of the model results is provided in Table 5-8.

FIGURE 5-6

Low-implementation Green Infrastructure Solution Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



Legend

Model Results | **Volume (cu. ft.)**

- Sufficient Capacity
- Surcharged
- Insufficient Freeboard
- 0.01 - 1,000
- 1,000 - 10,000
- 10,000 - 85,000
- Not Analyzed (Private, disconnected, upstream of runoff input)
- Subwatersheds
- Water Bodies
- Modeled Streams
- City of Alexandria Streams

Low Implementation of Green Infrastructure Model Results and High Priority Problem Areas
Task 4 Problem and Solution Identification and Prioritization for Hooffs Run

0 700 1,400 2,800
Feet

N

CH2MHILL

FIGURE 5-7
Medium-implementation Green Infrastructure Solution Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

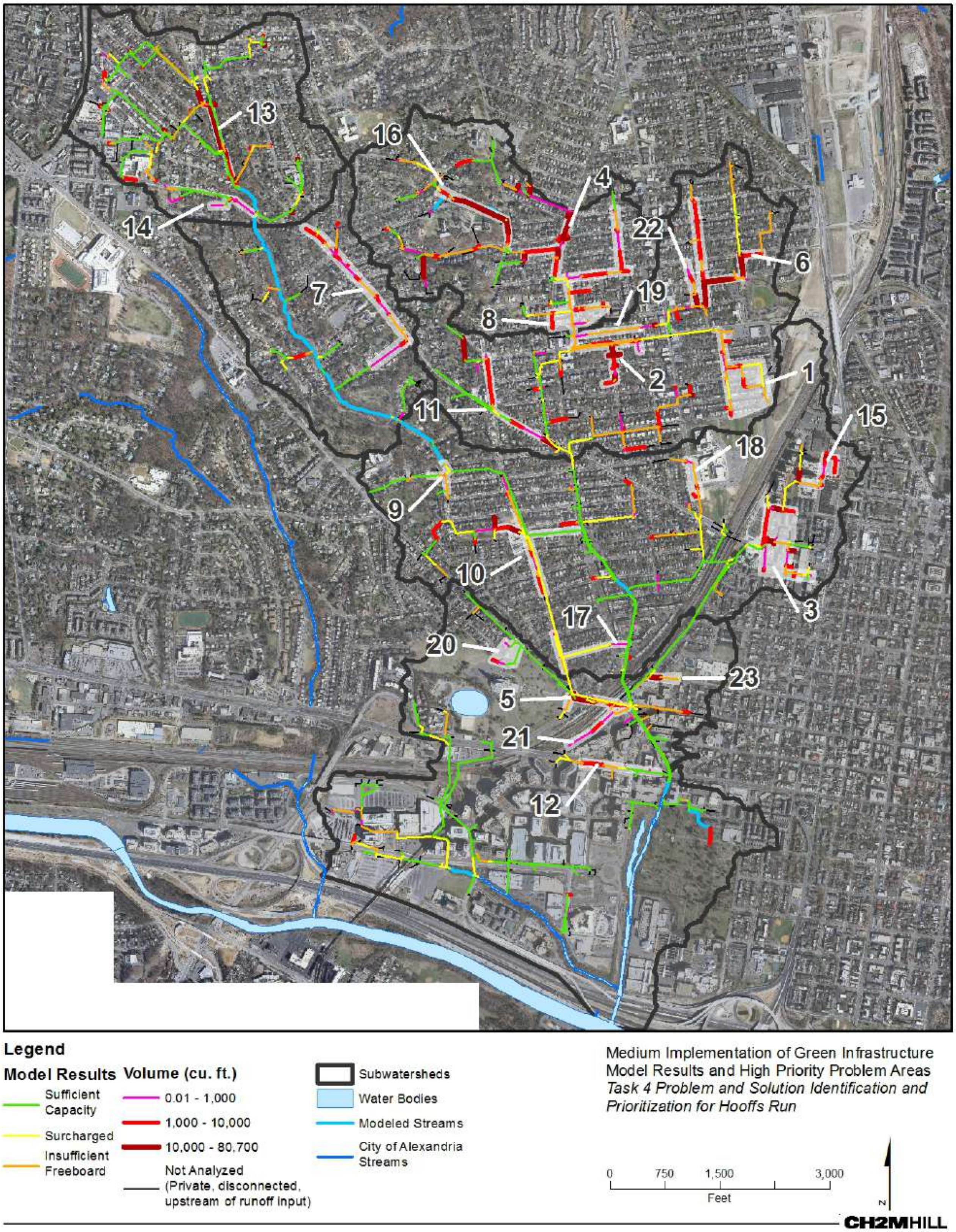


FIGURE 5-8
High-implementation Green Infrastructure Solution Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

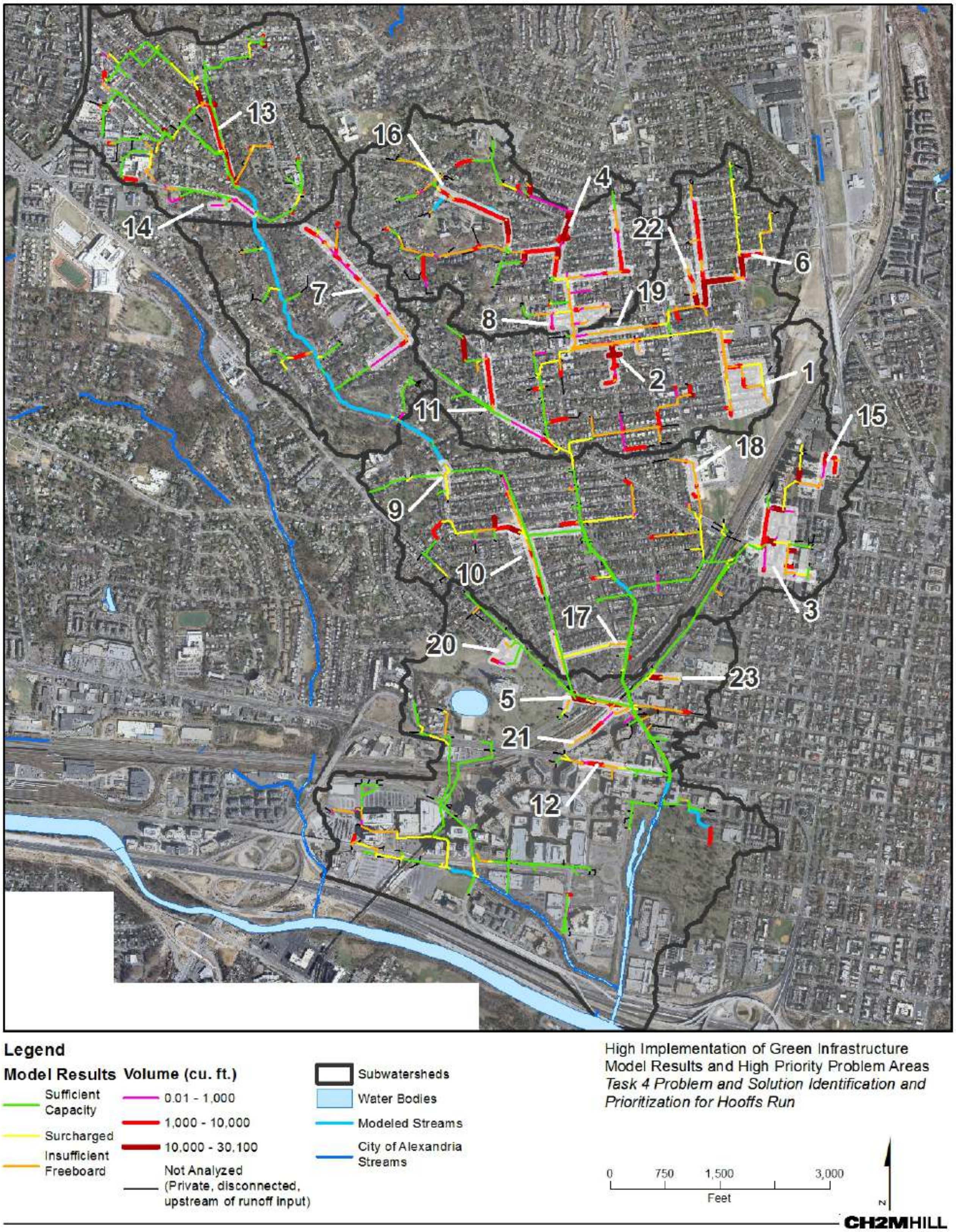


TABLE 5-8
Summary of Major Capacity and Green Infrastructure Implementation Model Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

	Major Capacity Results				Low Green Infrastructure Implementation Results				Medium Green Infrastructure Implementation Results				High Green Infrastructure Implementation Results			
	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]
Sufficient Capacity	53,672	37	-	-	54,192	37	-	-	56,810	39	-	-	63,485	44	-	-
Surcharged[a]	23,050	16	1,401	-	23,514	16	1,348	-	23,253	16	1,224	-	21,425	15	1,097	-
Insufficient Freeboard	30,436	21	-	-	31,100	21	-	-	31,787	22	-	-	30,595	21	-	-
Flooded	38,368	26	624	2,914,887	36,721	25	593	2,727,290	33,675	23	523	2,318,401	30,021	21	460	1,934,667

Notes:

Results presented for pipe segments are based on capacity at upstream end of pipe.

[a] Duration of surcharged flow includes time during which conduits have insufficient freeboard or are flooded at upstream end only.

[b] Flooded volume includes volume flooded at upstream end of the conduit.

Overall, model results indicate that green infrastructure is effective at reducing flood volumes and durations. On the low end, a 10 percent impervious reduction by low green infrastructure implementation reduces length of flooding in the network by about 1 percent and reduces the overall flood volume by about 6 percent. The duration of surcharge and flooding is also reduced slightly compared to the major conveyance solution results. At the high end, a 50 percent reduction in impervious area reduces length of flooding in the network by about 5 percent and reduces total flood volume by about 34 percent.

Results within each high-priority problem area are shown in Tables 5-9 and 5-10. On average, the flood volume was reduced by 13 percent in high-priority problem areas by the low green infrastructure implementation, 33 percent by the medium green infrastructure implementation, and about 50 percent by the high green infrastructure implementation. Peak flow results were less dramatic, with the low green infrastructure implementation reducing peak flow by about 0.6 percent on average, medium green infrastructure implementation reducing peak flow by about 2.5 percent, and high green infrastructure implementation reducing peak flow by over 5 percent.

TABLE 5-9
Green Infrastructure Solutions Flood Volume Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

		Low GI Implementation		Medium GI Implementation		High GI Implementation	
Problem Area ID	**Major Conveyance Flood Volume (MG)**	**Solution Flood Volume (MG)**	**Percent Reduction**	**Solution Flood Volume (MG)**	**Percent Reduction**	**Solution Flood Volume (MG)**	**Percent Reduction**
1	0.355	0.318	10	0.224	37	0.144	59
2	1.022	0.966	5	0.858	16	0.758	26
3	1.248	1.173	6	1.016	19	0.866	31
4	2.909	2.784	4	2.552	12	2.310	21
5	1.283	1.242	3	1.112	13	0.998	22
6	2.250	2.114	6	1.818	19	1.543	31
7	0.290	0.275	5	0.244	16	0.212	27
8	0.133	0.113	15	0.073	45	0.036	73
9	0.003	0.000	93	0.000	99	-	100
10	0.394	0.344	13	0.259	34	0.196	50
11	0.377	0.339	10	0.263	30	0.187	50
12	0.142	0.130	8	0.094	34	0.055	61
13	0.912	0.855	6	0.726	20	0.579	37
14	0.182	0.170	6	0.145	20	0.116	36
15	0.415	0.397	4	0.304	27	0.228	45
16	0.620	0.593	4	0.531	14	0.458	26
17	0.035	0.025	29	0.008	77	0.000	100
18	0.195	0.170	13	0.119	39	0.069	65
19	0.001	0.000	24	0.000	60	0.000	76
20	0.037	0.034	9	0.028	26	0.023	40
21	0.126	0.115	9	0.084	33	0.061	51
22	0.362	0.339	6	0.266	26	0.208	42
23	0.421	0.373	11	0.285	32	0.202	52
		Average	**13**		**33**		**49**

TABLE 5-10
Green Infrastructure Solutions Peak Flow Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

		Low GI Implementation		Medium GI Implementation		High GI Implementation	
Problem Area ID	**Major Conveyance Peak Flow (cfs)**	**Solution Peak Flow (cfs)**	**Percent Reduction[a]**	**Solution Peak Flow (cfs)**	**Percent Reduction[a]**	**Solution Peak Flow (cfs)**	**Percent Reduction[a]**
1	56	56	0	55	2	54	3
2	10	10	0	10	1	10	2
3	57	57	0	56	1	56	2
4	143	143	0	140	2	137	4
5	51	53	-4	52	-2	52	-1
6	47	46	1	46	2	45	3
7	21	21	0	21	1	21	1
8	198	196	1	196	1	191	4
9	769	756	2	725	6	690	10
10	103	98	5	86	16	66	36
11	75	75	0	74	1	73	3
12	40	40	0	40	1	39	4
13	152	151	0	151	1	150	1
14	26	26	1	25	2	25	3
15	15	15	0	15	1	15	2
16	57	57	0	57	0	57	0
17	40	40	1	39	2	37	7
18	36	36	1	35	2	34	5
19	77	76	0	75	3	73	5
20	61	59	2	56	7	53	13
21	22	22	0	22	1	21	4
22	8	8	1	8	4	8	7
23	24	24	1	23	2	23	5
		Average	**1**		**2**		**5**

Note:
[a] Negative value in Percent Reduction column indicates an increase in flood volume.

SECTION 6

Alternatives Analysis and Prioritization

The goal of alternatives analysis and prioritization was to evaluate the cost and performance of the various solution approaches/technologies and develop watershed-wide alternatives aimed at resolving capacity related problems in the Hooffs Run Watershed. The solution identification process resulted in 111 unique projects for the 23 high-priority problem areas in the Hooffs Run Watershed. The alternatives analysis and prioritization was performed after completing the solution modeling for the high-priority problem areas. The following section describes the results of the alternatives analysis and prioritization.

6.1 Problem Area Benefit Analysis

The 111 solutions for the 23 high-priority problem areas were scored for the eight solution evaluation criteria:

- Urban drainage/flooding
- Environmental compliance
- Eco-City goals/sustainability
- Social benefits
- Integrated asset management
- City-wide maintenance implications
- Constructability
- Public acceptability

After completing preliminary scoring of all projects, City staff reviewed prioritization results to ensure the objectives of the analysis were being met. This review resulted in a minimum flood reduction threshold of 22 percent for all projects. If projects did not meet this minimum threshold, they were not included in the prioritization, though the scoring and costing data were maintained for documentation. Of the 111 solutions, 37 did not meet the minimum flood reduction threshold, leaving 75 projects.

Figures 6-1 through 6-3 show bar charts of the total benefit scores for each of these 75 projects. The horizontal axis has the project name, which is a combination of the problem area number and the technology/solution approach type. For example, CONV-1 is the conveyance solution for problem area 1; STOR-1 is the storage solution; and LGI-1, MGI-1, and HGI-1 are the low, medium, and high green infrastructure implementations, respectively. The charts show all solutions included in the prioritization (that is, all solutions providing at least 22 percent reduction in flooding) by problem area in ascending order from left to right.

A full table of the scoring and alternatives analysis results is included in Appendix E.

FIGURE 6-1
Total Benefit Score Chart for High-priority Problem Areas 1 through 8
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

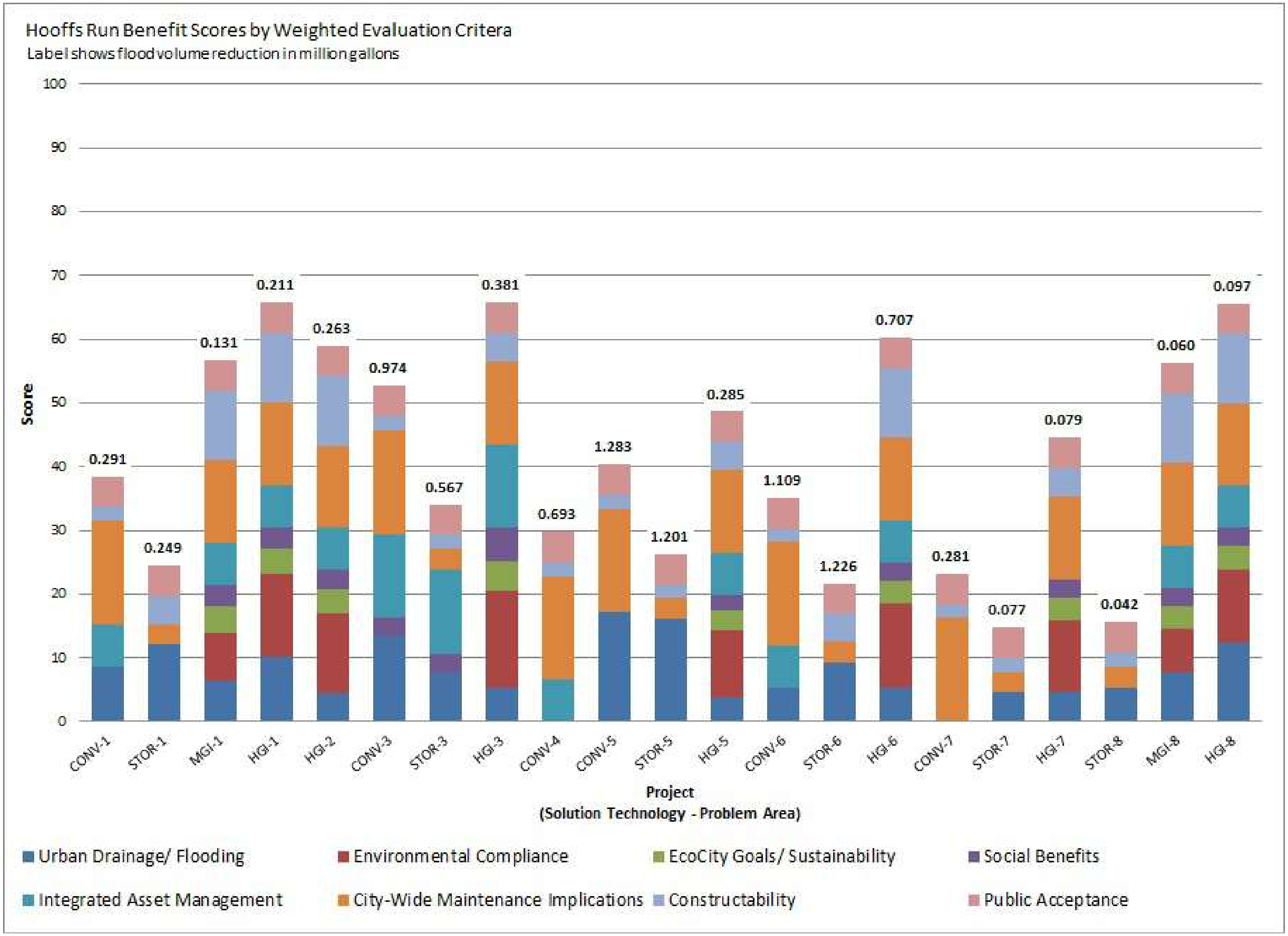


FIGURE 6-2
Total Benefit Score Chart for High-priority Problem Areas 9 through 16
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

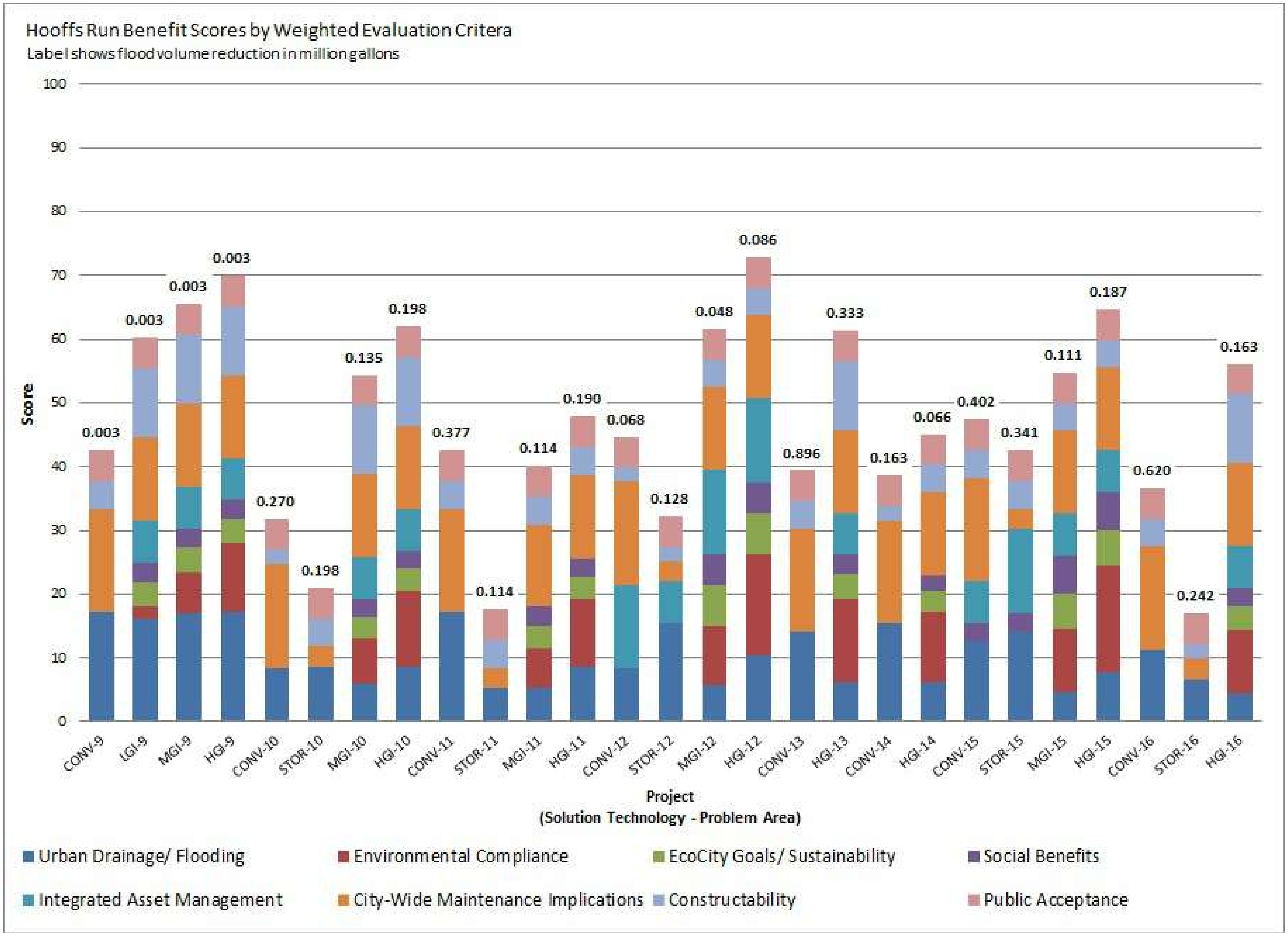
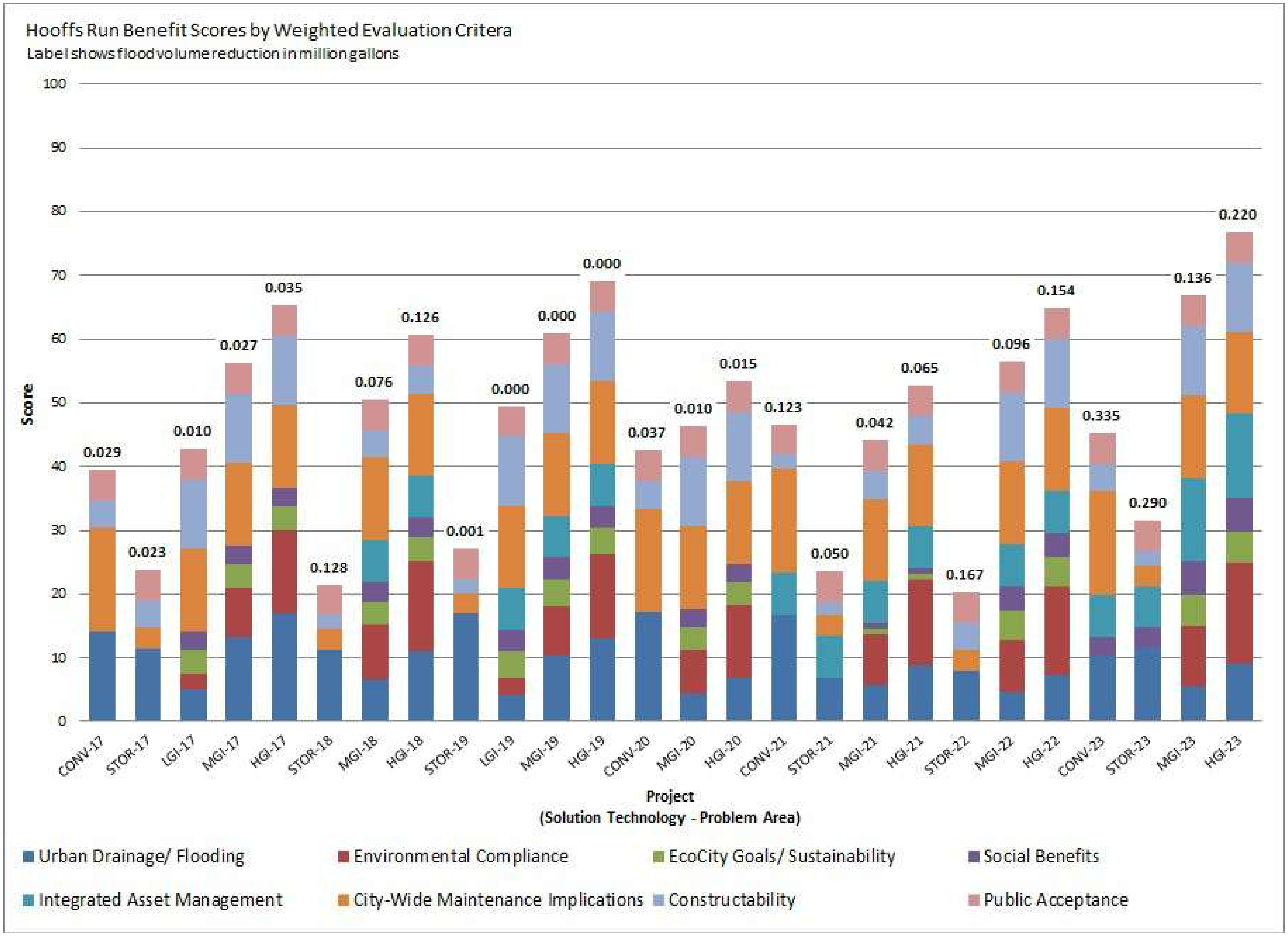


FIGURE 6-3
Total Benefit Score Chart for High-priority Problem Areas 17 through 23
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



6.2 Problem Area Solution Costs

Planning-level capital costs, which include construction as well as engineering and design and contingency, were developed for each of the 111 solutions. The basis of the costs information for each technology is provided in Appendix F. The basic unit costs used for costing the various projects were the same across all City infrastructure projects. Three levels of green infrastructure implementation were evaluated for this project:

- High Implementation – Manage 50% of total impervious area in the shed
- Medium Implementation – Manage 30% of total impervious area in the shed
- Low Implementation – Manage 10% of total impervious area in the shed

The unit cost of implementing GI at the various implementation levels is driven by the availability of GI opportunity areas. Since the GI opportunity areas varied across watersheds, the cost of implementation of the various levels of GI also varies across watersheds. Table 6-1 provides the construction cost assumptions for the low, medium, and high implementation levels of green infrastructure in Hooffs Run watershed based on implementing GI across the whole watershed.

TABLE 6-1
Green Infrastructure Construction Costs
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Green Infrastructure Level	Area Managed %	Area Managed Ac	Cost Per Acre Managed	Construction Cost
Low Green Infrastructure	10	80.0	$41,832	$3,346,585
Medium Green Infrastructure	30	240.0	$80,759	$19,382,210
High Green Infrastructure	50	400.0	$139,028	$55,611,316

Table 6-2 provides the capital cost in millions of dollars for all 111 solutions. Projects that do not meet the minimum threshold for flood reduction are shown in ***bold italics***.

TABLE 6-2
Capital Costs for High-priority Problem Area Solutions
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Problem Area	Conveyance	Storage (Conventional SWM)	Low Green Infrastructure	Medium Green Infrastructure	High Green Infrastructure
1	$2.35	$0.34	***$0.09***	$0.50	$1.44
2	***$0.63***	***$1.29***	***$0.05***	***$0.26***	$0.75
3	$1.27	$2.27	***$0.24***	***$1.37***	$3.93
4	$3.64	***$1.01***	***$0.38***	***$2.22***	***$6.37***
5	$0.72	$2.24	***$0.10***	***$0.58***	$1.67
6	$1.84	$2.30	***$0.15***	***$0.85***	$2.43
7	$1.47	$1.00	***$0.07***	***$0.41***	$1.17
8	***$3.28***	$0.11	***$0.44***	$2.54	$7.29
9	$0.16	N/A	$0.77	$4.48	$12.84
10	$0.85	$1.03	***$0.17***	$0.98	$2.81
11	$0.79	$0.34	***$0.08***	$0.45	$1.29
12	$0.28	$0.49	***$0.08***	$0.44	$1.26

TABLE 6-2
Capital Costs for High-priority Problem Area Solutions
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Problem Area	Conveyance	Storage (Conventional SWM)	Low Green Infrastructure	Medium Green Infrastructure	High Green Infrastructure
13	$1.01	N/A	***$0.33***	***$1.93***	$5.53
14	$0.14	N/A	***$0.03***	***$0.16***	$0.45
15	$0.52	$0.83	***$0.06***	$0.33	$0.95
16	$0.87	$0.39	***$0.07***	***$0.40***	$1.16
17	$0.42	$0.40	$0.05	$0.27	$0.77
18	***$0.17***	$0.33	***$0.04***	$0.26	$0.74
19	***$0.99***	$0.10	$0.23	$1.35	$3.87
20	$0.17	N/A	***$0.02***	$0.12	$0.34
21	$0.25	$0.45	***$0.03***	$0.18	$0.52
22	***$0.16***	$0.26	***$0.02***	$0.12	$0.33
23	$0.20	$0.60	***$0.06***	$0.32	$0.93

Note: Costs shown in ***bold italics*** are for projects that do not meet the 22 percent minimum flood reduction threshold set by the City.
Costs are in millions of dollars.

6.3 Problem Area Benefit/Cost Results

The benefit/cost score is the ratio of the total benefit divided by the total capital cost in millions of dollars. This metric indicates the cost efficiency of a project and can help direct resources to the projects that will provide the greatest benefit for the lowest cost. Cost benefit results are presented in Figures 6-4 through 6-6. The charts show only projects meeting the 22 percent minimum flood reduction threshold and are presented by problem area in ascending order from left to right on the horizontal access.

The benefit/cost score is shown as a bar chart in blue. Additionally, the cost per gallon of flood reduction is included as a line on a logarithmic scale. This metric provides an alternative cost-based method for ranking projects. It is important to remember that the best projects will have a high benefit/cost score but a low cost per gallon of flood reduction.

Figure 6-4
Benefit/Cost Chart for High-priority Problem Areas 1 through 8
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

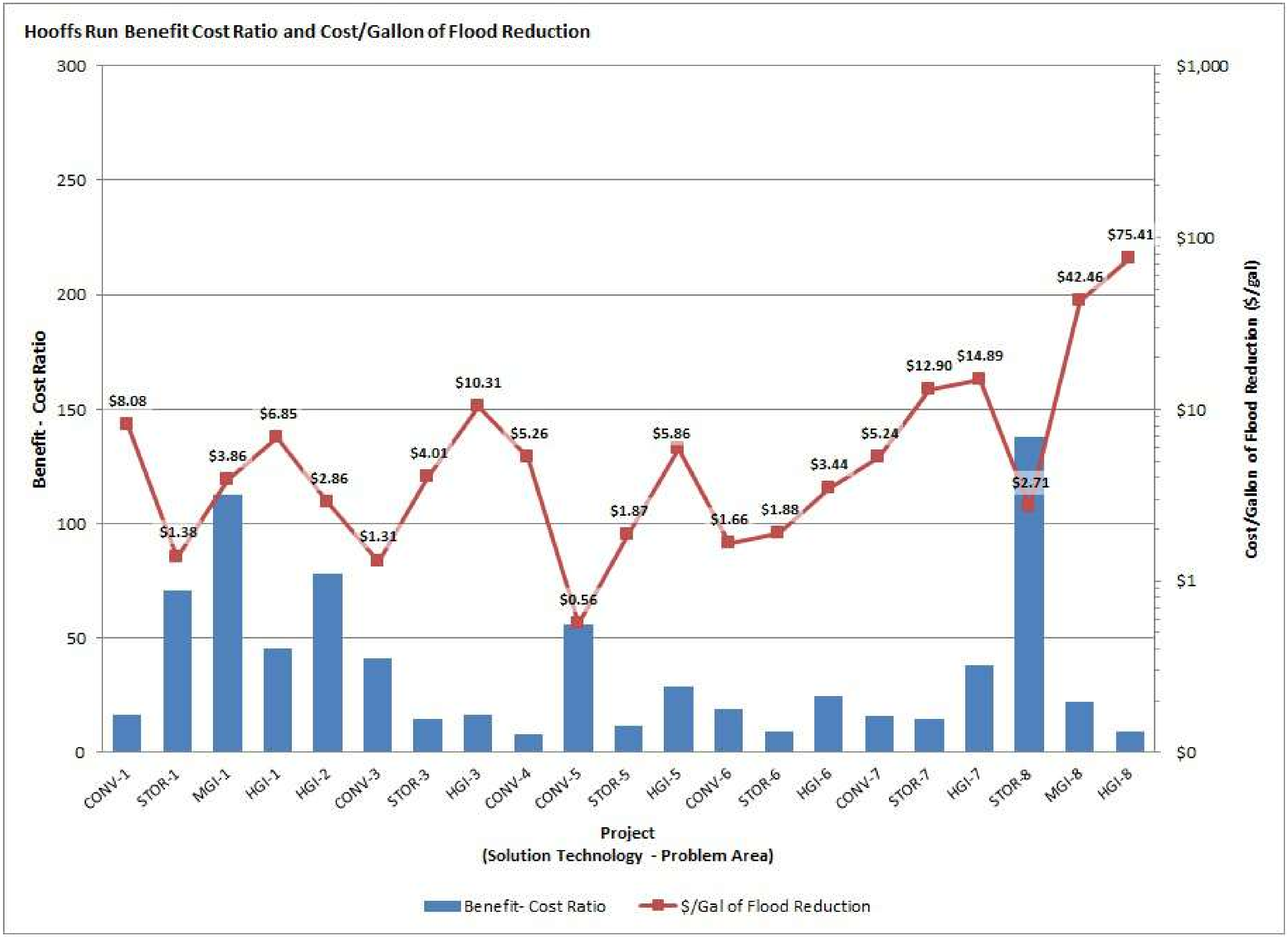


FIGURE 6-5
Benefit/Cost Chart for High-priority Problem Areas 9 through 16
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

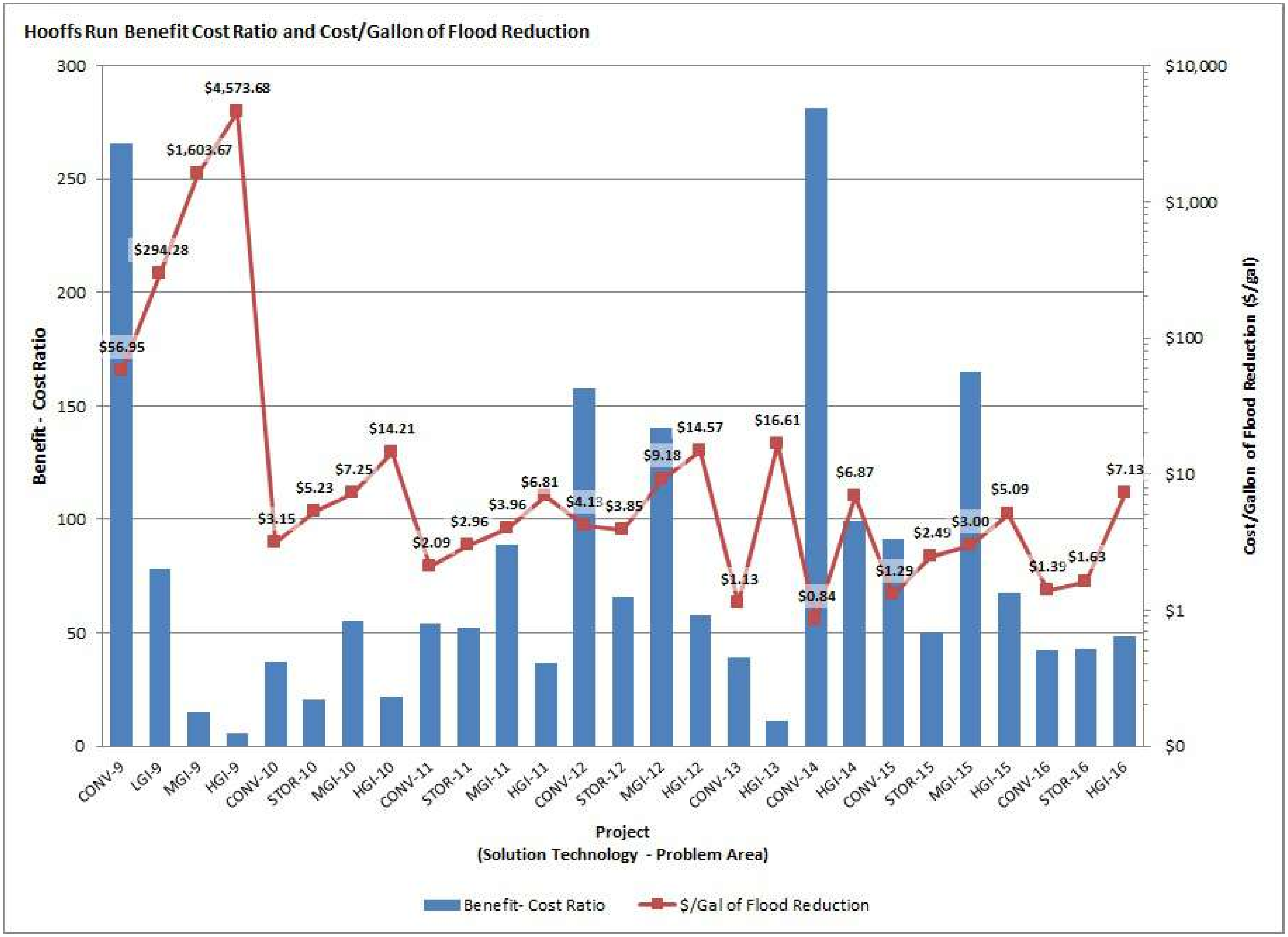
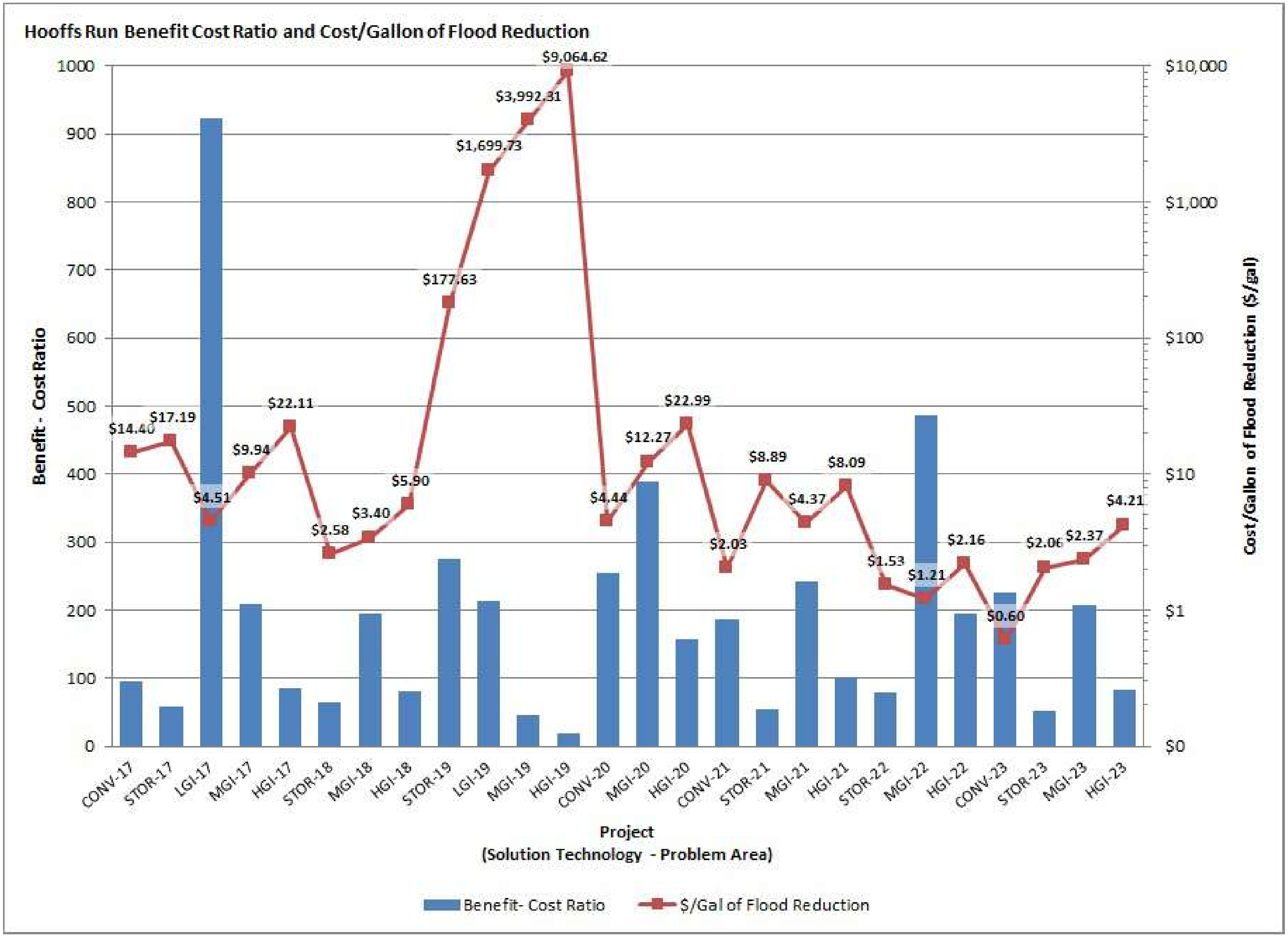


FIGURE 6-6
Benefit/Cost Chart for High-priority Problem Areas 17 through 23
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



6.4 Watershed-wide Alternatives

Three watershed-wide alternatives were developed for Hooffs Run. Each watershed-wide alternative was aimed at resolving capacity-related issues while also meeting a second goal: including maximizing cost-efficiency or benefit cost or targeting the highest-priority problems. The three alternatives examined include:

- Alternative 1: Most cost-effective solution for each problem area (lowest dollar-per-gallon of flood reduction)
- Alternative 2: Best benefit/cost ratio for each problem area (highest benefit/cost ratio)
- Alternative 3: Combination of best projects to resolve the highest-priority problem areas

Projects were selected for each of the watershed-wide alternatives based on the five individual technology-specific modeling results (Conveyance, Storage, and Low GI, Medium GI, and High GI implementation). A new model including the selected projects was run for each alternative. Results for the watershed-wide model runs are presented in section 6.4.4 and 6.4.5.

6.4.1 Alternative 1: Cost Efficiency

The first alternative focused on providing the best cost efficiency in each problem area. After removing projects that did not meet the minimum flood reduction threshold of 22 percent, the remaining projects were ranked by cost-per-gallon of flood reduction within each problem area in ascending order. The highest-ranked project, which was the project with the lowest cost-per-gallon of flood reduction, was selected for each problem area. Table 6-3 shows the selected project for each problem area based on the results from the technology based model runs. This alternative consisted primarily of conveyance solutions with a few green infrastructure and storage projects. Model results for this alternative are summarized in Table 6-7 and presented on Figure 6-7.

The watershed-wide model results of this alternative show that flooding was not decreased in problem areas 8, 19, and 22 when the 23 projects shown in Table 6-3 were simulated together. Conveyance solutions, while reducing flooding in an upstream problem area, increase peak flow out of the problem area and therefore may increase flows into downstream problem areas. In this alternative, the selected solution for problem areas 8 and 19 was storage and medium GI for problem area 22. Because conveyance capacity was not also increased in these problem areas, the increased peak flow experienced at these locations due to conveyance projects upstream caused additional flooding within the problem areas, even while storage and GI solutions were implemented. These downstream impacts are captured in Table 6-7, which summarizes each watershed-wide alternative.

TABLE 6-3
Selected Projects for Watershed-wide Alternative 1: Cost Efficiency
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Problem Area ID	Solution Technology	Project Name	Capital Cost ($M)	Benefit-Cost Ratio	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)
1	Storage	STOR-1	$0.34	70.8	0.249	70	$1.38
2	High GI	HGI-2	$0.75	78.5	0.263	26	$2.86
3	Conveyance	CONV-3	$1.27	41.4	0.974	78	$1.31
4	Conveyance	CONV-4	$3.64	8.17	0.693	24	$5.26
5	Conveyance	CONV-5	$0.72	56.2	1.283	100	$0.56
6	Conveyance	CONV-6	$1.84	19.1	1.109	49	$1.66
7	Conveyance	CONV-7	$1.47	15.7	0.281	97	$5.24
8	Storage	STOR-8	$0.11	137.8	0.042	31	$2.71

TABLE 6-3
Selected Projects for Watershed-wide Alternative 1: Cost Efficiency
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Problem Area ID	Solution Technology	Project Name	Capital Cost ($M)	Benefit-Cost Ratio	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)
9	Conveyance	CONV-9	$0.16	265.9	0.003	100	$56.95
10	Conveyance	CONV-10	$0.85	37.3	0.270	68	$3.15
11	Conveyance	CONV-11	$0.79	54.0	0.377	100	$2.09
12	Storage	STOR-12	$0.49	65.7	0.128	90	$3.85
13	Conveyance	CONV-13	$1.01	39.0	0.896	98	$1.13
14	Conveyance	CONV-14	$0.14	281.3	0.163	90	$0.84
15	Conveyance	CONV-15	$0.52	91.5	0.402	97	$1.29
16	Conveyance	CONV-16	$0.87	42.3	0.620	100	$1.39
17	Low GI	LGI-17	$0.05	922.1	0.010	29	$4.51
18	Storage	STOR-18	$0.33	65.0	0.128	66	$2.58
19	Storage	STOR-19	$0.11	274.9	0.001	99	$177.63
20	Conveyance	CONV-20	$0.17	255.6	0.037	100	$4.44
21	Conveyance	CONV-21	$0.25	186.2	0.123	98	$2.03
22	Medium GI	MGI-22	$0.12	486.8	0.096	26	$1.21
23	Conveyance	CONV-23	$0.20	225.4	0.335	80	$0.60
		Total	**$16.18**		**8.48** [a]	**62**	**$1.91**

Notes:
Results presented in this table are based on separate technology based model runs (Conveyance, Storage, and Low, Med, and High GI)
[a] Existing flood volume for Problem Areas 1 through 23 is 13.71 MG.

6.4.2 Alternative 2: Benefit/Cost

The second alternative focused on providing the best benefit/cost in each problem area. After removing projects that did not meet the minimum flood reduction threshold of 22 percent, the remaining projects were ranked by benefit/cost in descending order within each problem area. The highest-ranked project in each of the 23 problem areas, which was the project with the highest benefit/cost score, was selected. Table 6-4 shows the selected project for each problem area. This alternative consisted primarily of conveyance and medium and high green infrastructure projects. Model results are summarized in Table 6-7 and presented on Figure 6-8.

Similar to Alternative 1, problem areas 8, 19, and 22 experienced an increase in flooding after implementing the selected solutions due to their location downstream of other problem areas and location just upstream of the central artery of Hooffs Culvert. Because the storage and green infrastructure solutions were selected based on results generated in a model that included all 23 storage solutions and a model that included all 23 green infrastructure solutions respectively, the solutions cannot be expected to provide the same flood reduction performance when paired with conveyance solutions in upstream problem areas. These downstream impacts are captured in Table 6-7, which summarizes each watershed-wide alternative.

TABLE 6-4
Selected Projects for Watershed-wide Alternative 2: Benefit/Cost
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Problem Area ID	Solution Technology	Project Name	Capital Cost ($M)	Benefit-Cost Ratio	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)
1	Medium GI	MGI-1	$0.50	112.5	0.131	37	$3.86
2	High GI	HGI-2	$0.75	78.5	0.263	26	$2.86
3	Conveyance	CONV-3	$1.27	41.4	0.974	78	$1.31
4	Conveyance	CONV-4	$3.64	8.2	0.693	24	$5.26
5	Conveyance	CONV-5	$0.72	56.2	1.283	100	$0.56
6	High GI	HGI-6	$2.43	24.8	0.707	31	$3.44
7	High GI	HGI-7	$1.17	37.9	0.079	27	$14.89
8	Storage	STOR-8	$0.11	137.8	0.042	31	$2.71
9	Conveyance	CONV-9	$0.16	265.9	0.003	100	$56.95
10	Medium GI	MGI-10	$0.98	55.5	0.135	34	$7.25
11	Medium GI	MGI-11	$0.45	88.8	0.114	30	$3.96
12	Conveyance	CONV-12	$0.28	158.0	0.068	48	$4.13
13	Conveyance	CONV-13	$1.01	39.0	0.896	98	$1.13
14	Conveyance	CONV-14	$0.14	281.3	0.163	90	$0.84
15	Medium GI	MGI-15	$0.33	165.1	0.111	27	$3.00
16	High GI	HGI-16	$1.16	48.4	0.163	26	$7.13
17	Low GI	LGI-17	$0.05	922.1	0.010	29	$4.51
18	Medium GI	MGI-18	$0.26	195.3	0.076	39	$3.40
19	Storage	STOR-19	$0.10	274.9	0.001	99	$177.63
20	Medium GI	MGI-20	$0.12	390.0	0.010	26	$12.27
21	Medium GI	MGI-21	$0.18	242.3	0.042	33	$4.37
22	Medium GI	MGI-22	$0.12	486.8	0.096	26	$1.21
23	Conveyance	CONV-23	$0.20	225.4	0.335	80	$0.60
		Total	**$16.14**		**6.39** [a]	**47**	**$2.52**

Notes:
Results presented in this table are based on separate technology based model runs (Conveyance, Storage, and Low, Med, and High GI)
[a] Existing flood volume for Problem Areas 1 through 23 is 13.71 MG.

6.4.3 Alternative 3: Highest-priority Problems

The third alternative focused on resolving the highest-priority problems by combining multiple solutions within a problem area. The minimum threshold on flood reduction was removed because the goal was to eliminate as much flooding as possible from the problem area. In some cases, the combination of a storage or conveyance project that offered substantial flood reduction combined with a project such as low green infrastructure, which offered less than 22 percent flood reduction, could eliminate flooding within a problem area. The best combination of solutions in terms of cost efficiency, benefit/cost, and overall flood reduction were compiled to attempt to resolve the worst problem areas. Because 23 project were recommended in Alternatives 1 and 2 (one per project area), 23 projects were selected for Alternative 3 to keep all three alternatives relatively consistent in scale. A total of 23 projects were selected for Problem Areas 1 through 14. Table 6-5 shows the selected project for each problem area. Model results are summarized in Table 6-7 and presented in Figure 30.

TABLE 6-5
Selected Projects for Watershed-wide Alternative 3: Highest-priority Problems
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

Problem Area ID	Solution Technology	Project Name	Capital Cost ($M)	Benefit-Cost Ratio	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)
1	Storage	STOR-1	$0.34	70.8	0.249	70	$1.38
1	Medium GI	MGI-1	$0.50	112.5	0.131	37	$3.86
2	Conveyance	CONV-2	$0.63	47.0	0.189	18	$3.36
2	High GI	HGI-2	$0.75	78.5	0.263	26	$2.86
3	Conveyance	CONV-3	$1.27	41.4	0.974	78	$1.31
3	Medium GI	MGI-3	$1.37	41.8	0.231	19	$5.92
4	Storage	STOR-4	$1.01	12.84	0.469	16	$2.15
5	Conveyance	CONV-5	$0.72	56.2	1.283	100	$0.56
6	Storage	STOR-6	$2.30	9.4	1.226	54	$1.88
6	Medium GI	MGI-6	$0.85	62.3	0.431	19	$1.96
7	Conveyance	CONV-7	$1.47	15.7	0.281	97	$5.24
7	Low GI	LGI-7	$0.07	449.0	0.015	5	$4.72
8	Storage	STOR-8	$0.11	137.8	0.042	31	$2.71
8	Medium GI	MGI-8	$2.54	22.2	0.060	45	$42.46
10	Conveyance	CONV-10	$0.85	37.3	0.270	68	$3.15
10	Low GI	LGI-10	$0.17	270.7	0.049	13	$3.44
11	Conveyance	CONV-11	$0.79	54.0	0.377	100	$2.09
12	Storage	STOR-12	$0.49	65.7	0.128	90	$3.85
12	Low GI	LGI-12	$0.08	671.0	0.011	8	$6.68
13	Conveyance	CONV-13	$1.01	39.0	0.896	98	$1.13
13	Low GI	LGI-13	$0.33	137.5	0.056	6	$5.91
14	Conveyance	CONV-14	$0.14	281.3	0.163	90	$0.84
14	Low GI	LGI-14	$0.03	1149.9	0.012	6	$2.34
		Total	**$17.83**		**7.81[a]**	**68**	**$2.28**

Notes:
Results presented in this table are based on separate technology based model runs (Conveyance, Storage, and Low, Med, and High GI)
[a] Existing flood volume for Problem Areas 1 through 14 is 11.50 MG.

6.4.4 Modeling Results

Table 6-6 provides a summary of the hydraulic model results for the three watershed-wide alternatives. Alternative 3, which focuses on resolving the highest-priority problems, provides the greatest reduction of flooding in the system in terms of total length of pipe experiencing flooding and also minimizes the duration of surcharging and flooding. However, Alternative 1 minimizes the total volume of flooding in the system overall. Maps comparing the model results are presented on Figures 6-7 through 6-9.

Each of the alternatives analyzed leaves areas with flooding (as shown by red lines on the maps), largely because those areas are outside the boundaries of the high-priority problem areas. These areas were not addressed by solutions because they were either flooding at isolated structures, or did not score high based on the problem area scoring criteria.

TABLE 6-6
Summary of Watershed-wide Alternative Model Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

	Major Capacity Results				Alternative 1 Best Cost Efficiency				Alternative 2 Best Benefit/Cost Ratio				Alternative 3 Highest-priority Problems			
	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]
Sufficient Capacity	53,672	37	-	-	63,656	44	-	-	59,850	41	-	-	60,208	42	-	-
Surcharged[a]	23,050	16	1,401	-	24,672	17	840	-	22,944	16	1,040	-	22,909	16	881	-
Insufficient Freeboard	30,436	21	-	-	27,668	19	-	-	31,673	22	-	-	30,114	21	-	-
Flooded	38,368	26	624	2,914,887	29,226	20	344	1,954,594	31,036	21	422	1,770,088	31,592	22	323	1,709,864

Notes:
Results presented for pipe segments are based on capacity at upstream end of pipe.
[a] Duration of surcharged flow includes time during which conduits have insufficient freeboard or are flooded at upstream end only.
[b] Flooded volume includes volume flooded at upstream end of the conduit.

FIGURE 6-7
Alternative 1: Cost-efficiency Model Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

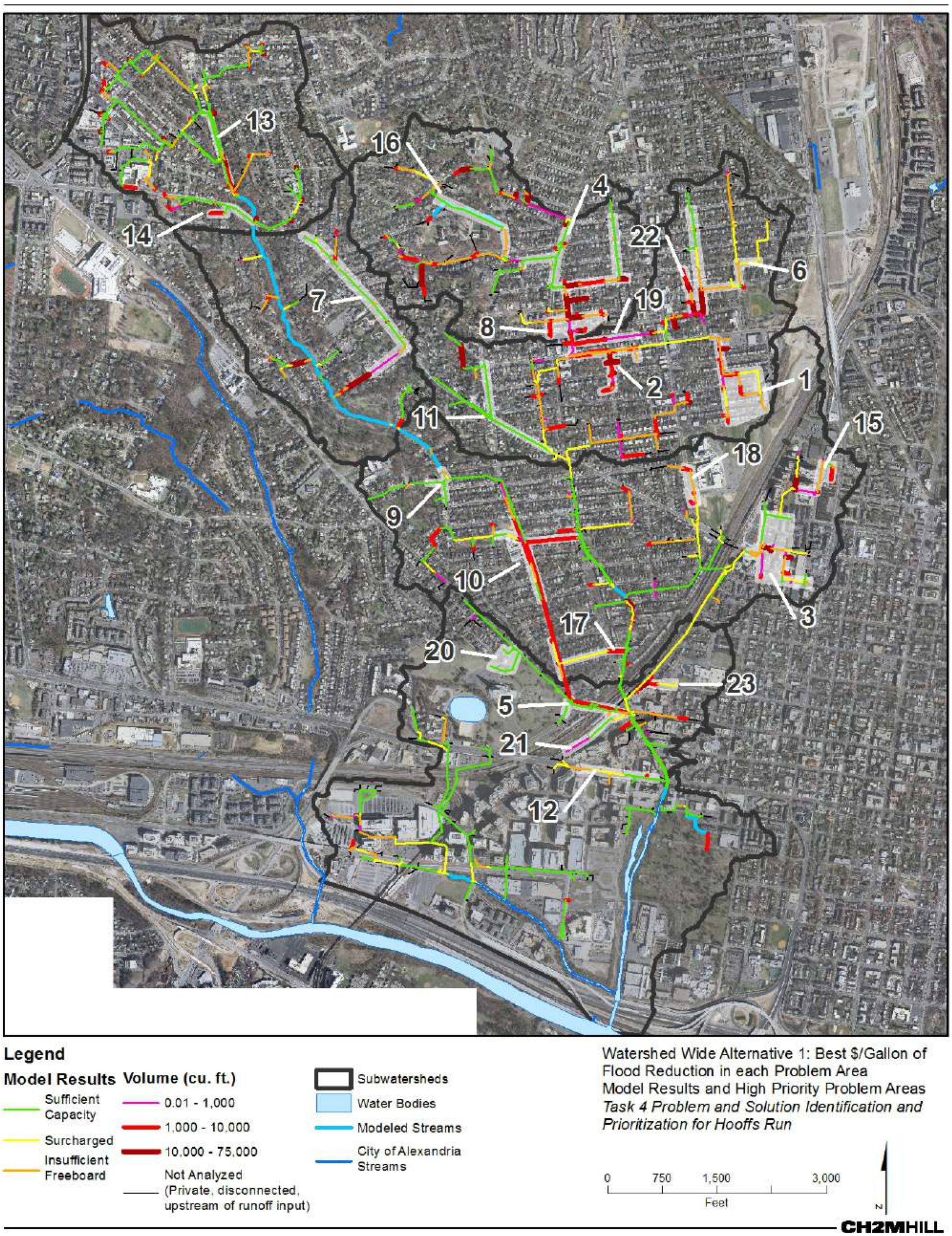


FIGURE 6-8
Alternative 2: Benefit/Cost Model Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

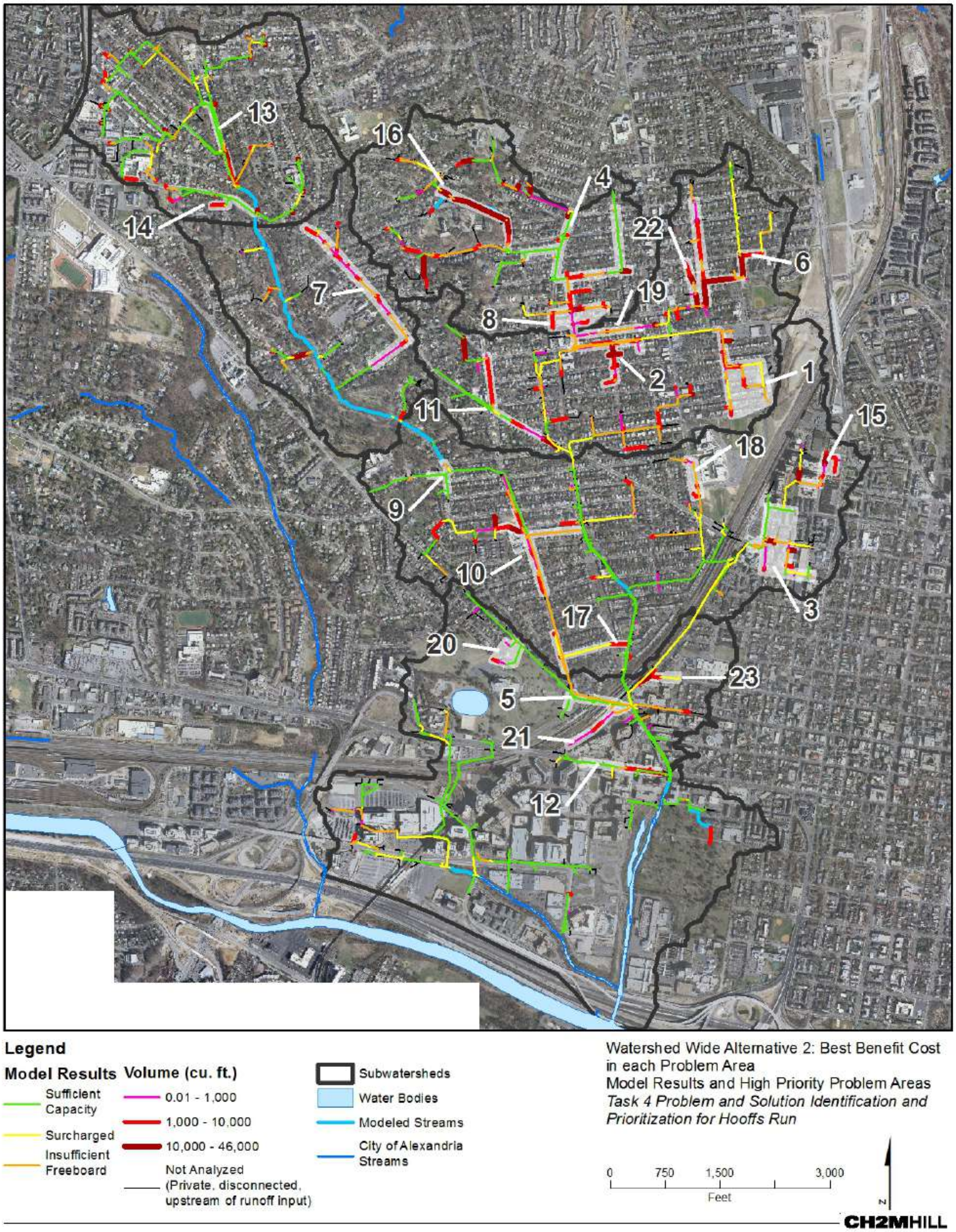
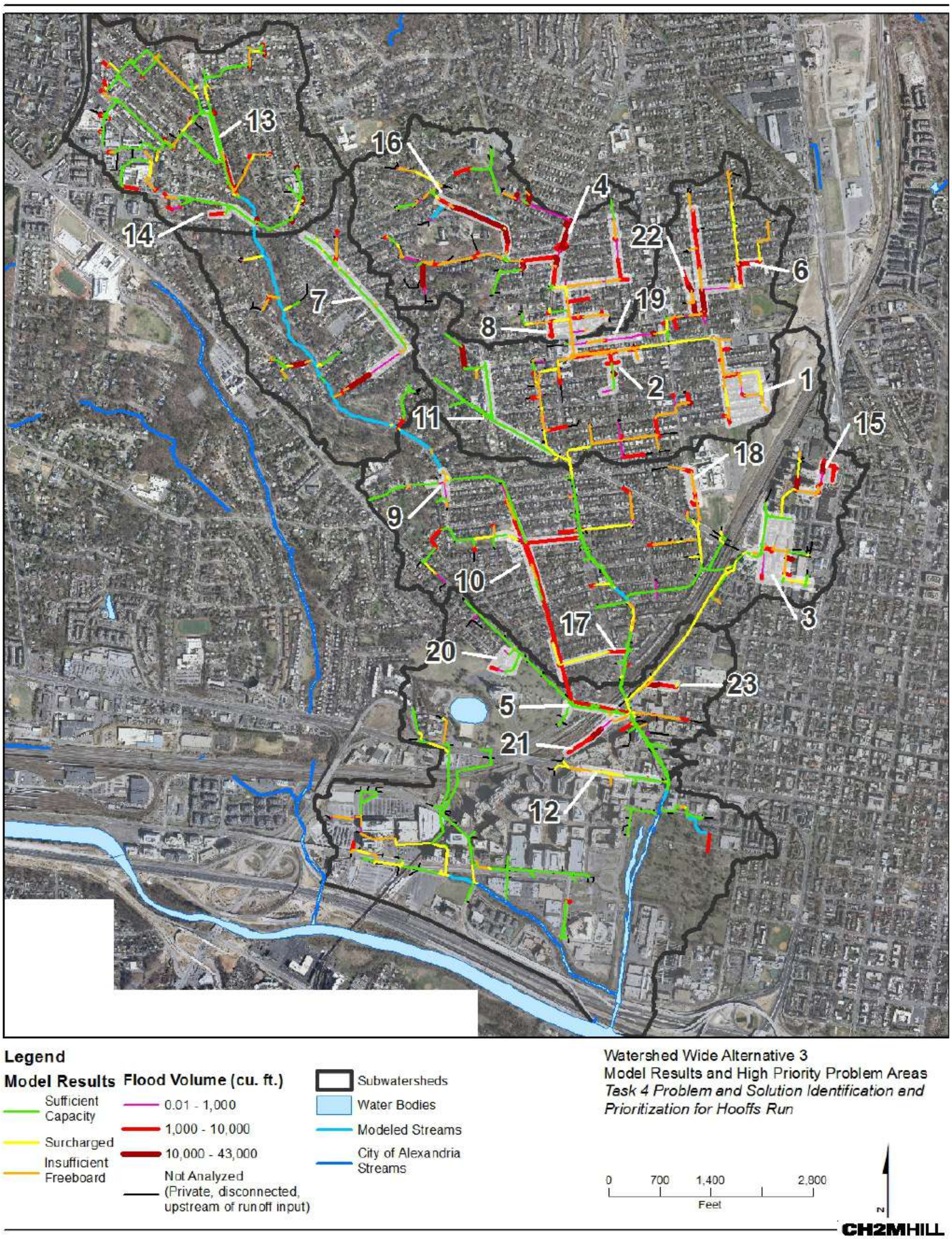


FIGURE 6-9
Alternative 3: Highest-priority Problem Areas Model Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



6.4.5 Scoring and Prioritization Results

The results for each alternative generally reflect the objective of that particular alternative. A summary of the results is provided in Table 6-7 below. A model was run for each of the alternatives, so the alternative-specific results presented in Table 6-7 may differ slightly from the results generated from the technology-specific model runs used to evaluate each solution type.

A summary of the results is provided in Table 6-7. Though Alternative 1 included the solution with the lowest cost per gallon of flood reduction for each problem area from the initial model runs, it is not the most cost effective watershed-wide alternative. Alternative 3 was focused on providing relief in the 14 highest-priority problem areas that have more substantial flooding than problem areas 15 through 23, and greater flood reduction was achieved for a slightly lower cost in Alternative 3. Therefore, Alternative 3 was the most cost effective watershed-wide alternative at $2.48 per gallon of flood reduction. Alternative 2 provides the highest total benefit score, though these scores are only slightly higher than Alterative 3, which offers slightly more flood reduction and focuses on the worst problem areas as defined by the problem identification scoring. Alternative 3 was selected as the most beneficial and cost effective watershed-wide alternative.

TABLE 6-7
Watershed-wide Alternatives Scoring and Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run

	Alternative 1 - Best Cost Efficiency	Alternative 2 - Best Benefit/Cost Ratio	Alternative 3 – Highest-priority Problems
Total Capital Cost ($ Millions)	$19.65	$18.10	$18.26
Total Benefit Score	811	984	978
Overall Benefit/Cost	41	54	54
Total Flood Reduction (MG)	6.90	6.82	7.36
Cost of Flood Reduction ($/gallon)	$2.85	$2.65	$2.48

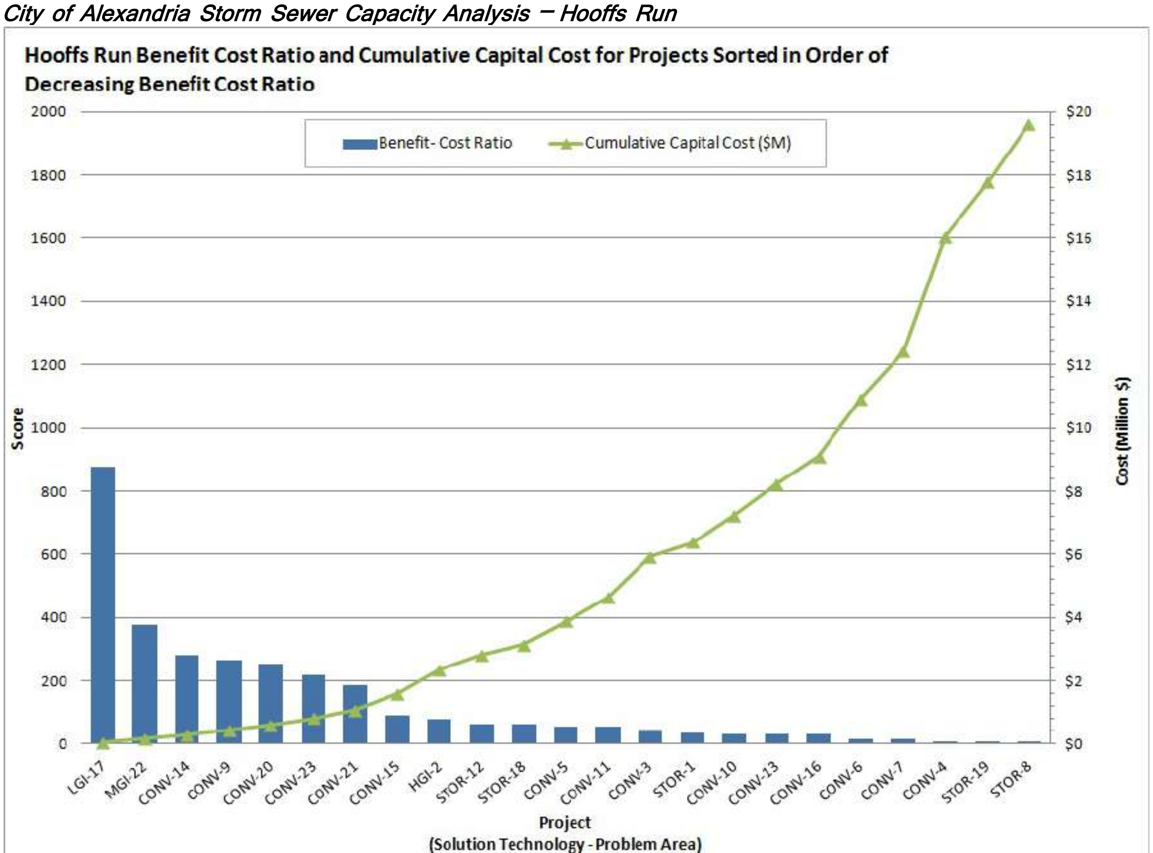
Note:
Results presented in this table are based on watershed-wide alternative models that include the selected projects documented in sections 5.4.1-5.4.3.

When developing a capital improvement plan, the benefit cost or cost efficiency ($/gallon of flood reduction) are typically used to guide the order in which projects are implemented. Prioritization results for the three watershed-wide alternatives are presented in Figures 6-10 through 6-12. The top chart shows the benefit cost ratio and the cumulative capital cost of the alternative. The solutions are provided in order of decreasing benefit cost ratio; solutions with the greatest benefit cost ratio are presented on the left and solutions with the lowest benefit cost ratio are presented on the right.

The bottom chart shows the benefit/cost ratio for each solution in the watershed-wide alternative in order of increasing cost/gallon of flood reduction. In watershed-wide scenarios 1 and 2, the best cost efficiency and best benefit/cost ratio alternatives, there are 3 or 4 green infrastructure and storage solutions that have no value for the cost/gallon of flood reduction. These solutions, shown on right side of the chart, are in problem areas that experience an increase in flooding after implementing the projects selected for the watershed-wide alternative. In both alternatives the selection of a conveyance solution upstream and/or downstream of these 3 or 4 problem areas increases peak flow upstream and backwater downstream of these problem areas, which contributes to an increase in flooding elsewhere in the system.

Both charts show the cumulative capital cost plotted on the secondary axis. The solutions on both charts are named by the technology: conveyance (CONV), storage (STOR), low green infrastructure (LGI), medium GI (MGI), or high GI (HGI), and the problem area number.

FIGURE 6-10
Alternative 1: Best Cost Efficiency Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



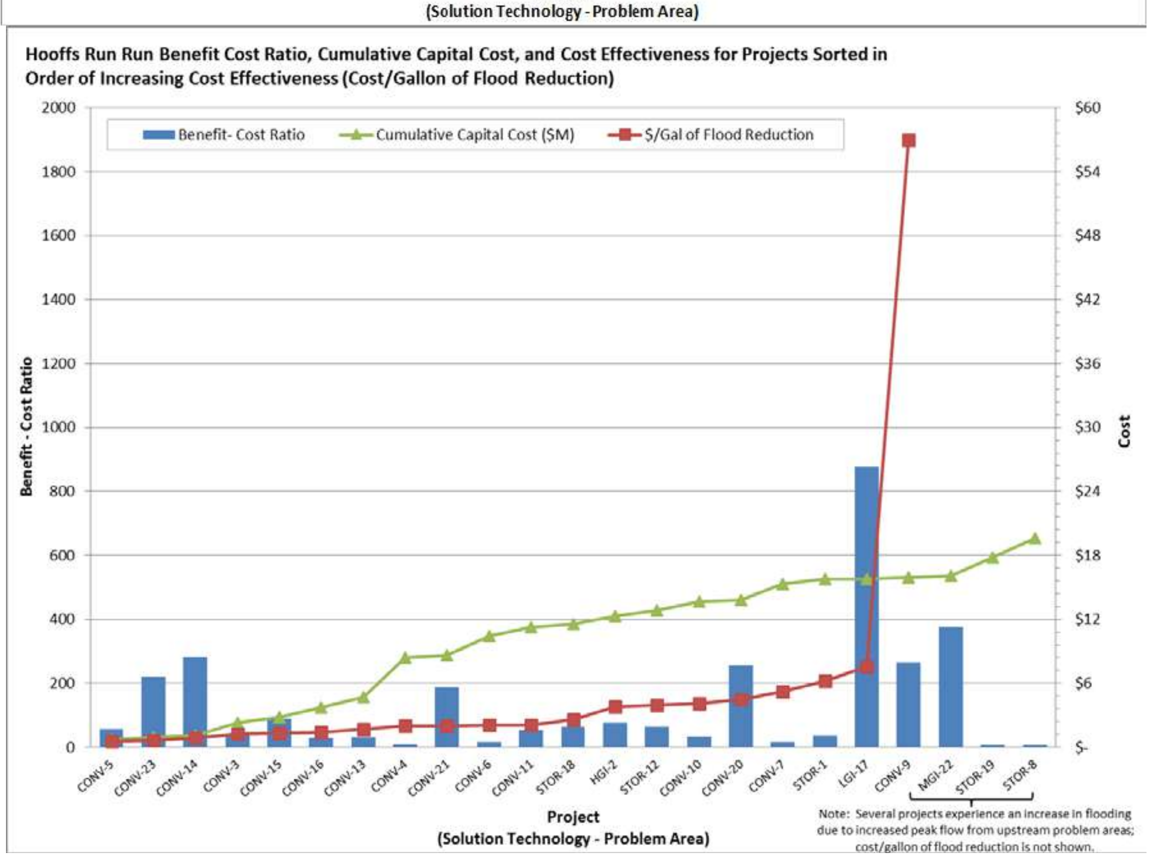
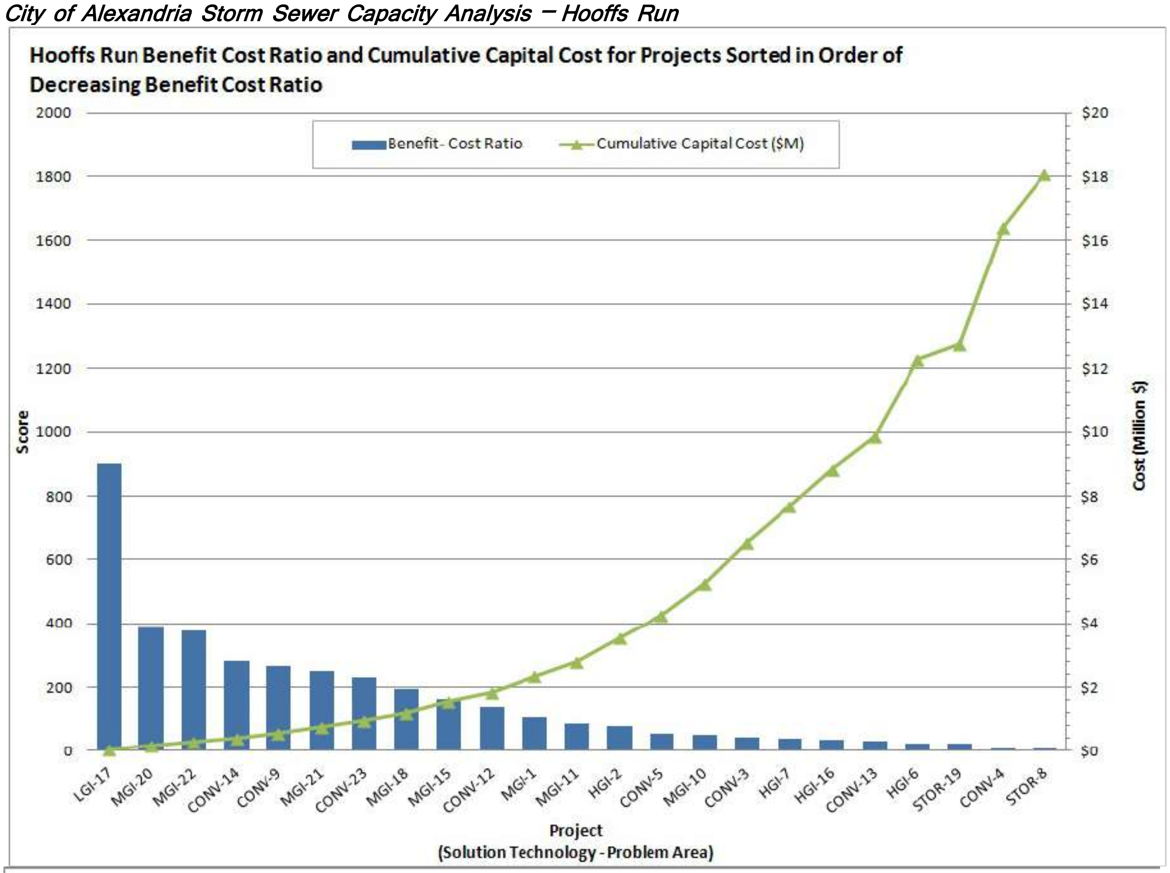


FIGURE 6-11
Alternative 2: Best Benefit/Cost Ratio Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run



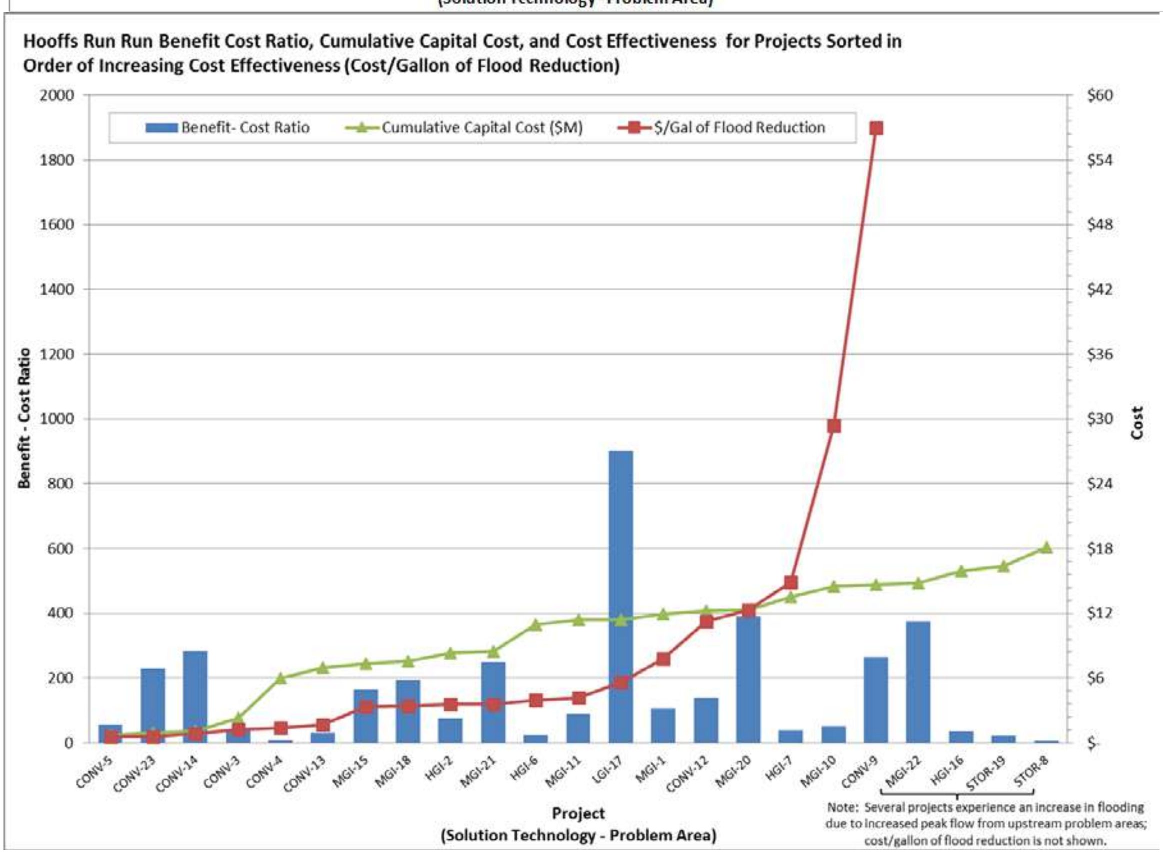
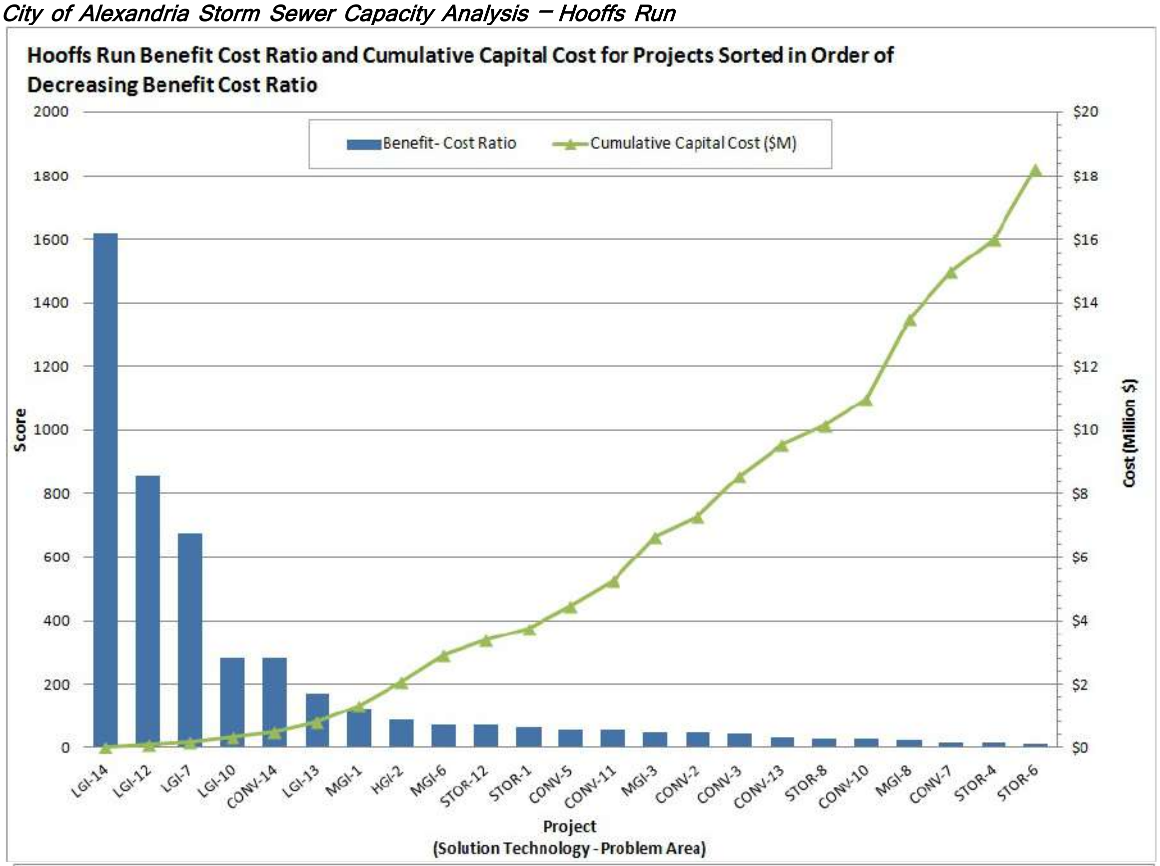
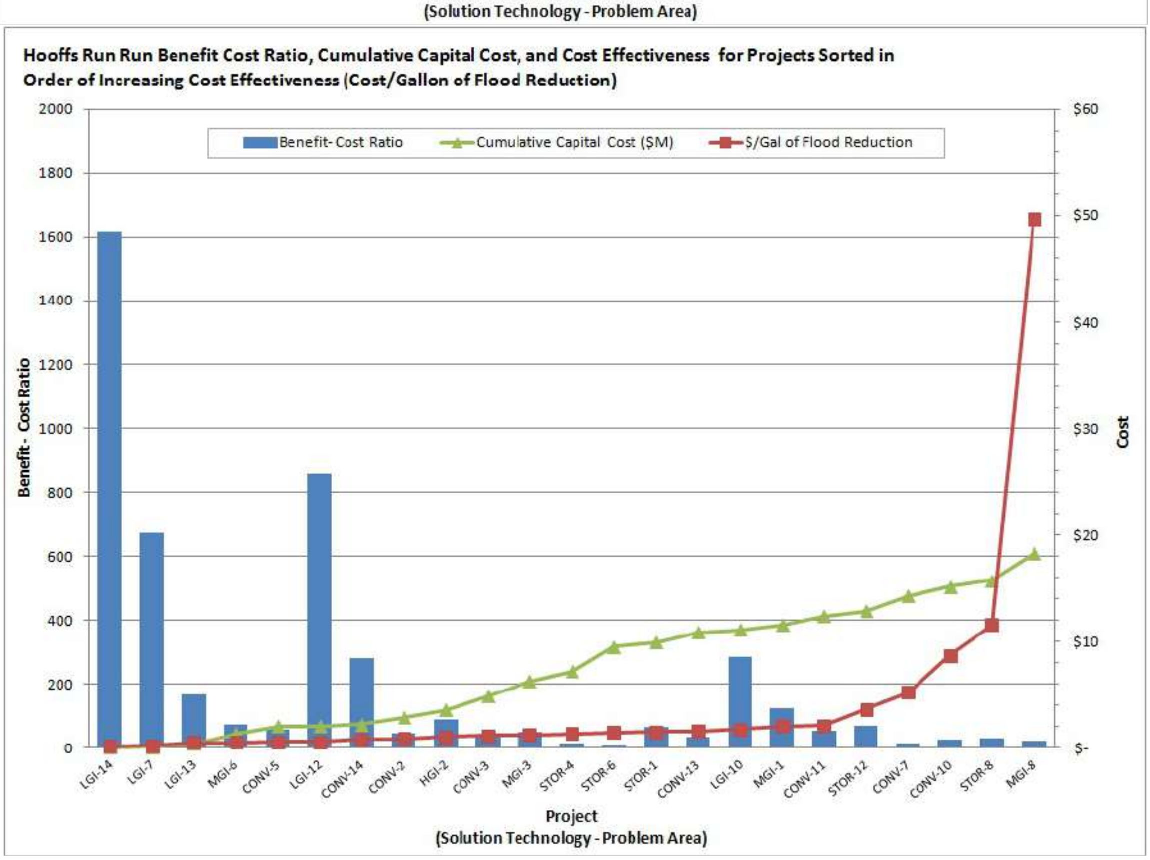


FIGURE 6-12
Alternative 3: Highest-priority Problems Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run





SECTION 7

Summary

The objectives of this phase of the study were to (1) identify and prioritize capacity problems based on modeling results from Task 2 of this project, and (2) develop and prioritize solutions to address those problems. The first objective was accomplished in two steps. The first objective included evaluation of each stormwater junction in the drainage network using a scoring system to identify problems based on several criteria, including the severity of flooding, proximity to critical infrastructure and roadways, identification of problems by city staff and the public, and opportunity for overland relief. In the next step of this objective, high-scoring junctions (that is, higher priority problems) were grouped together to form high-priority problem areas. In total, 23 high-priority problem areas were identified in the Hooffs Run watershed.

The second objective involved developing and prioritizing solutions to address capacity limitations within the 23 high-priority problem areas. Several different strategies were examined to accomplish this objective, including improving conveyance by increasing hydraulic capacity, reducing capacity limitations by adding distributed storage to the system, and reducing stormwater inflows by implementing green infrastructure. Each of these strategies required a different modeling approach. Conveyance improvements were modeled by increasing pipe diameter in key locations within the problem area, storage was added as storage nodes based on a preliminary siting exercise, and green infrastructure was modeled as a reduction in impervious area at three different implementation levels: high, medium, and low. A single model run was set up and run for each strategy addressing all 23 high-priority problem areas and the results were compiled for the alternative and prioritization evaluation. Solutions were evaluated based on several criteria, including drainage improvement/flood reduction, environmental compliance, sustainability and social benefits, asset management and maintenance implications, constructability, and public acceptance. Planning-level capital costs were developed for each solution to facilitate a benefit cost analysis and prioritization process.

The results of the solution identification and prioritization analysis show the following:

- In terms of solution technology performance:
  - Green infrastructure generally has the greatest overall benefit as defined by the solution evaluation scoring system described in this report
  - Conveyance solutions and high implementation of green infrastructure generally provide the greatest flood reduction of the technologies/approaches analyzed in Hooffs Run
  - Combination of conveyance or storage projects and green infrastructure generally provides the greatest benefit and flood reduction
- In terms of costs:
  - Low level of green infrastructure implementation generally has the greatest cost/benefit score but did not usually meet minimum threshold for flood reduction
  - Conveyance and storage projects generally provide the most economical stormwater volume reduction in terms of dollars per gallon of flood reduction within a high-priority problem area
  - Combination of conveyance and green infrastructure generally provides the greatest overall benefit/cost score

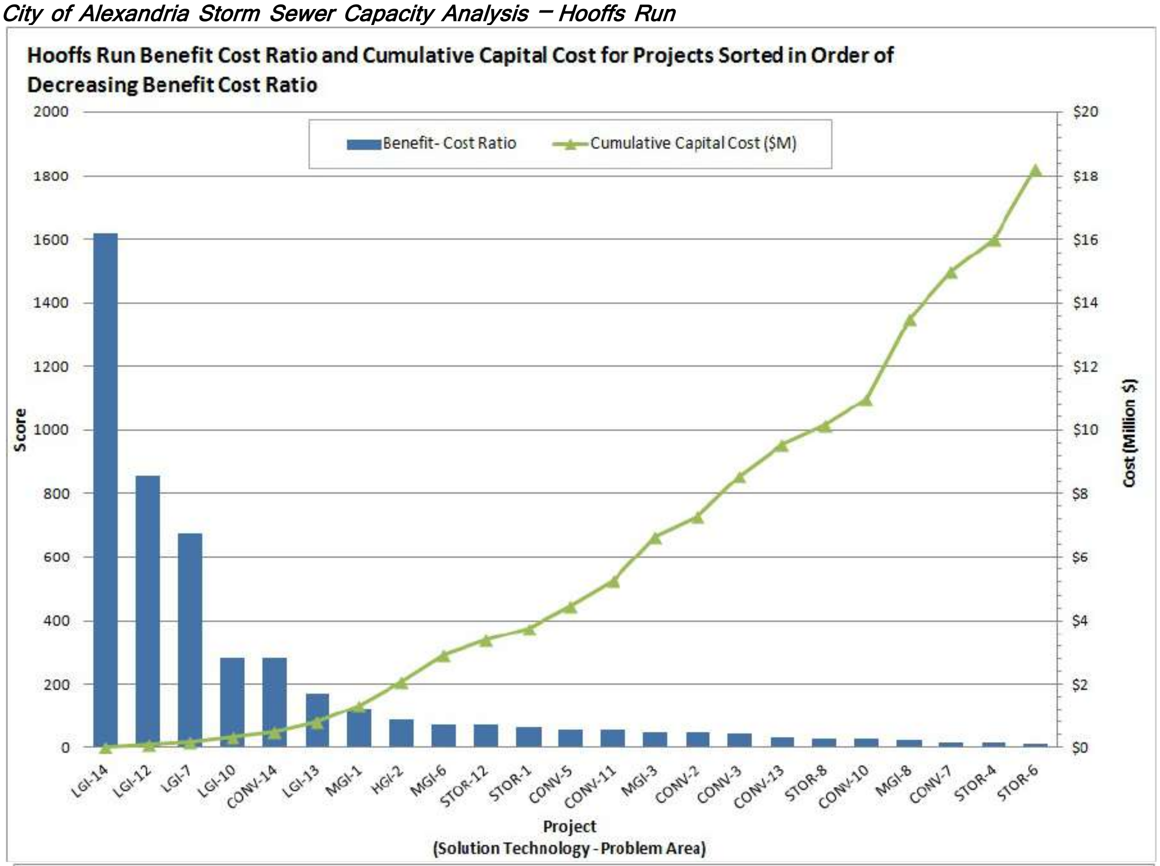
Three watershed-wide alternatives were developed, including:

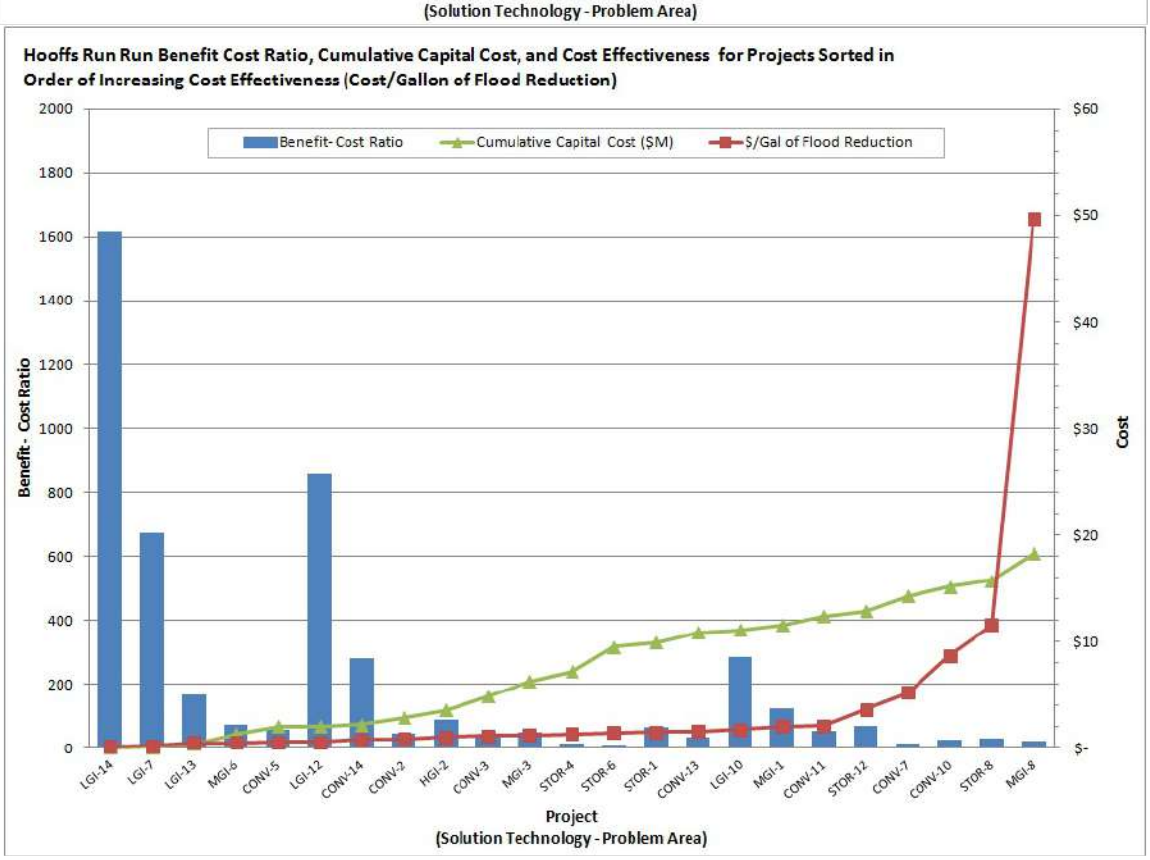
- Alternative 1: Most cost-effective solution for each problem area (lowest dollar-per-gallon of flood reduction)
- Alternative 2: Best benefit/cost ratio for each problem area (highest benefit/cost ratio)
- Alternative 3: Combination of best projects to resolve the worst problem areas

Though Alternative 1 included the solution with the lowest cost per gallon of flood reduction for each problem area from the initial model runs, it was not the most cost-effective watershed-wide alternative. Alternative 3 focuses on providing relief in the 14 highest-priority problem areas, which had more substantial flooding that the remaining 9 problem areas (15 through 23) and when compared to Alternative 1, greater flood reduction was achieved for a slightly lower cost in Alternative 3. Therefore, Alternative 3 is the most cost-effective watershed-wide alternative at $2.48 per gallon of flood reduction. Alternative 2 provides the highest total benefit score, though this score is only slightly higher than Alterative 3, which offers slightly more flood reduction and focuses on the worst problem areas as defined by the problem identification scoring. Alternative 3 was selected as the most beneficial and cost effective watershed-wide alternative. Two suggested prioritization of watershed-wide Alternative 3 projects are provided in Figure 7-1; projects can be prioritized either based on overall benefit/cost ratio or cost efficiency (cost per gallon of flood reduction).

It should be noted that the model does not include analysis on private property, but applies assumed runoff loads as inputs to the public conveyance system. The City chose not to include existing private or public stormwater management facilities upstream of the modeled collection system because of the limited available information on these facilities and a concern that the facilities may not be performing as designed. When the City moves forward into detailed evaluation and design of selected projects, it will be important to fully evaluate and account for the benefits of any existing stormwater management facilities.

FIGURE 7-1
Alternative 3: Highest-priority Problems Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Hooffs Run





SECTION 8

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Appendix A
Baseline Improvements

Appendix A - Baseline Improvements

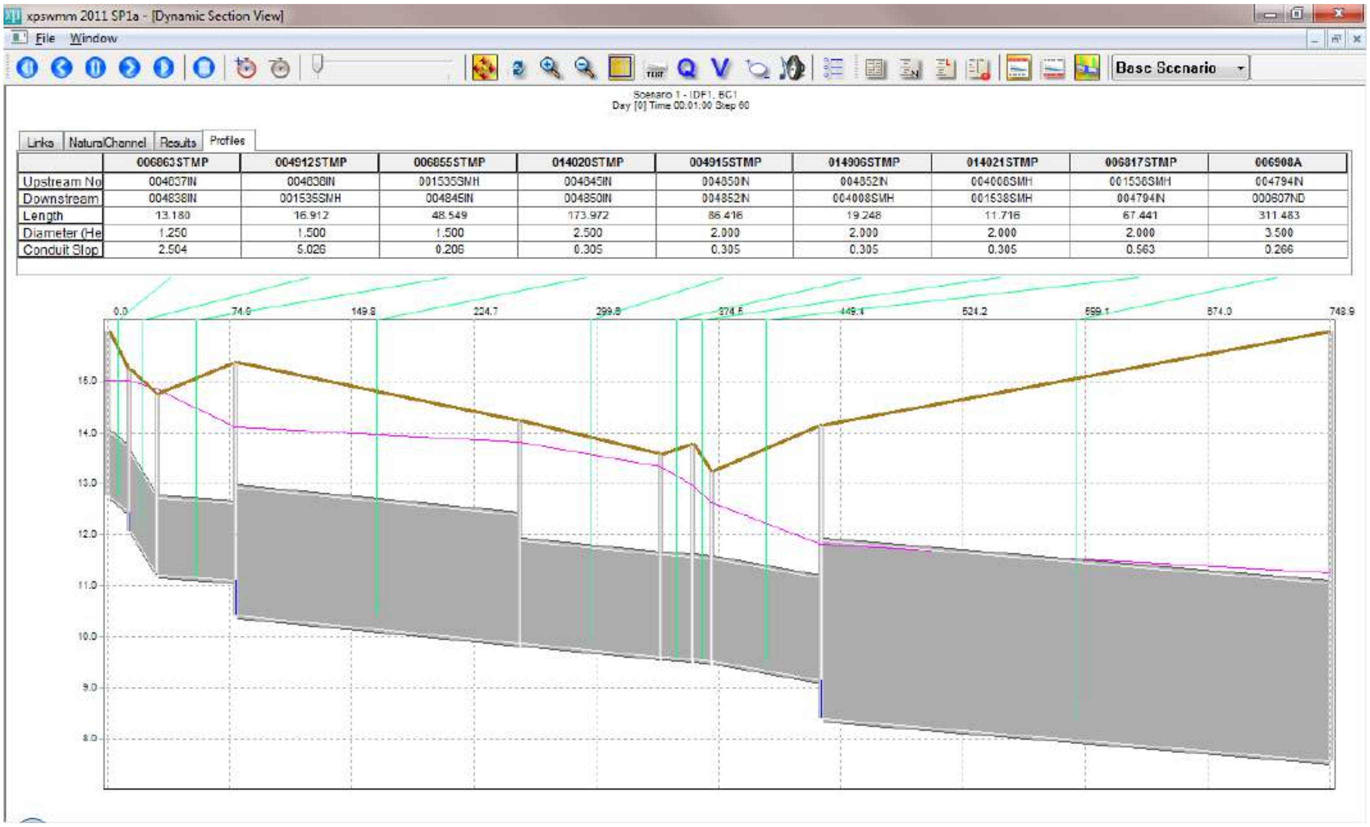
TABLE 1

Summary of Baseline Improvements

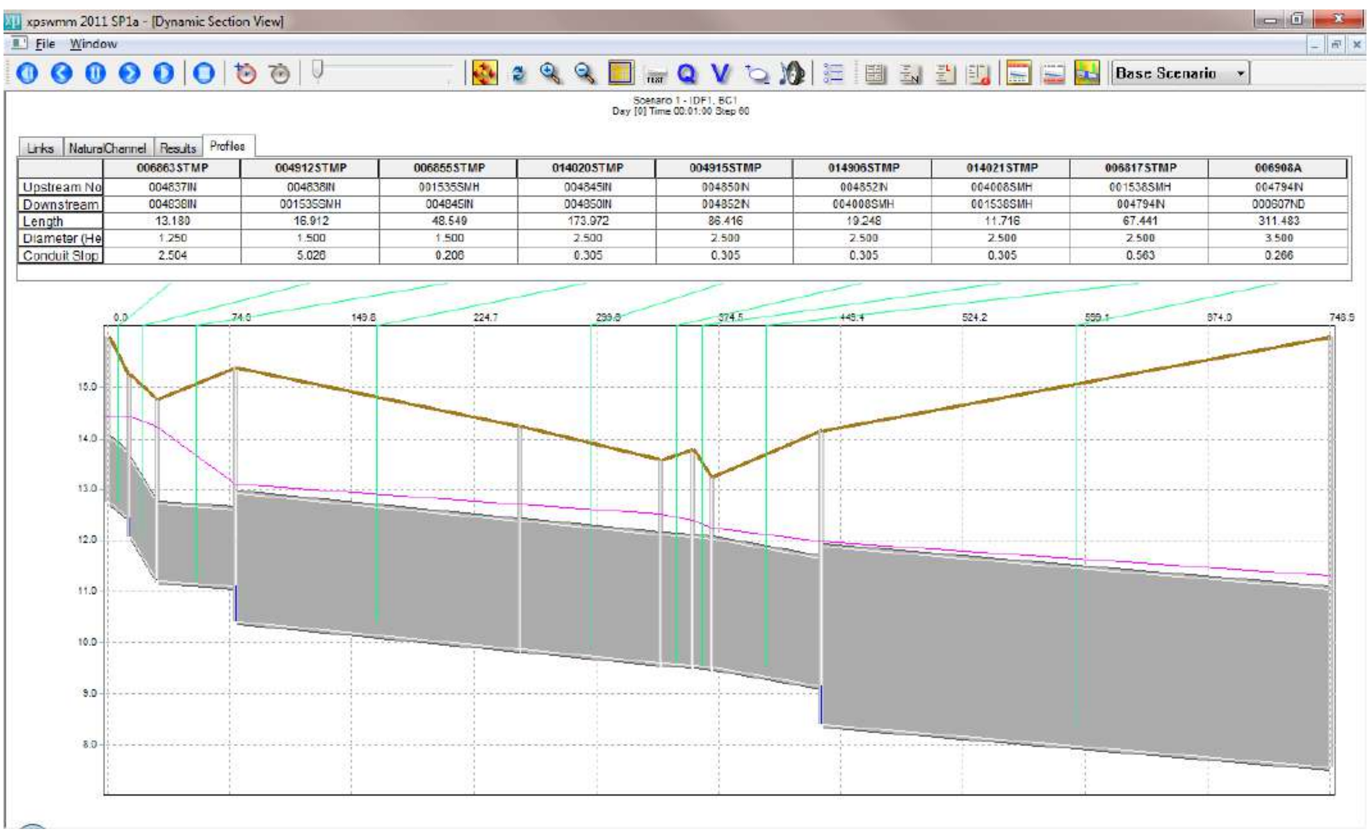
Baseline Project/ Figure Number	Issue	Resolution	Project Length (LF)	Project Cost ($)
1	Neck down	Increase diameter of 006817STMP, 014021STMP, 014906STMP, 004915STMP to 2.5 ft to match next upstream pipe (014020STMP).	185	$71,147
2	Neck down	Eliminate neck down by increasing diameter of 006873STMP to 5 ft to match next downstream pipe (006942A).	44	$36,437
3	Neck down	Eliminate neck down by increasing pipe diameter of 007006STMP to 4 ft to match next downstream pipe (007005STMP).	415	$275,595
4	Reverse slope	Adjust slope of 010248STMP, 010246B, 010246A to be consistent between next upstream and downstream pipes (010249A and 010236STMP respectively).	174	$45,964
5	Neck down	Increase diameter of 009315STMP and 009317STMP to 3.5 ft to match next upstream pipe (010483STMP).	56	$32,358
6	Steep slope, neck down, and reverse slope	Assume straight line slope between downstream ends of 009366STMP and 008410STMP and increase diameter of 010572A, 010572B, and 008410STMP to 2.0 ft to match next downstream pipe (008409STMP).	451	$99,043
7	Odd configuration	Adjust slope to be constant between 010444STMP and 010441STMP. NOTE: This area was not surveyed therefore it will be listed as a baseline project, but specifically called out as requiring field verification.	162	$31,114
8	Neck down and reverse slope	Increase pipe diameter of 010614STMP, 010617STMP, 010618B, 010618A, and 009482STMP to 3.5 feet to match downstream and upstream pipe diameters (010613STMP and 009517B respectively). Smooth slope between 010613STMP and 009517B (about 0.686%). Adjust size and slope of 009483STMP, located between 009482STMP and 009485STMP.	190	$107,625
9	Neck down	Increase diameter of 009483STMP to 3.5 ft to match changes downstream (see Figure 8). Adjust slope of 009483STMP to be a straight line between 009483STMP and 009519B (009519B has the lowest invert at manhole 003170SMH). Increase diameter of 009485STMP to match upstream pipe (009486STMP). See Figure 6 for other changes in the area.	233	$128,229

Figure 1

Increase diameter of 006817STMP, 014021STMP, 014906STMP, 004915STMP to 2.5 ft to match next upstream pipe (014020STMP).



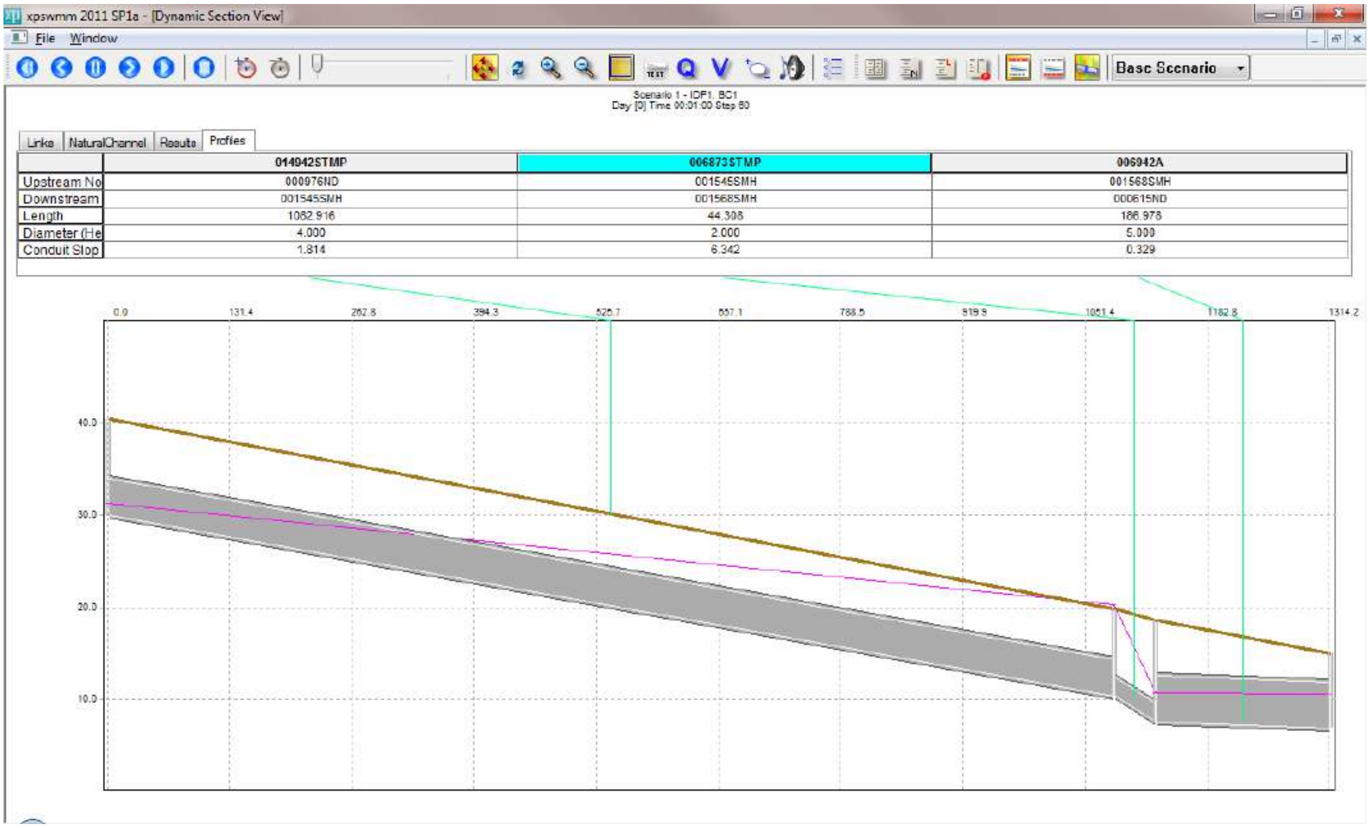
	006863STMP	004912STMP	006855STMP	014020STMP	004915STMP	014906STMP	014021STMP	006817STMP	006908A
Upstream No	004837IN	004838IN	001535SMH	004845IN	004850IN	004852IN	004008SMH	001538SMH	004794IN
Downstream	004838IN	001535SMH	004845IN	004850IN	004852IN	004008SMH	001538SMH	004794IN	000607ND
Length	13.180	16.912	48.549	173.972	86.416	19.248	11.716	67.441	311.483
Diameter (He	1.250	1.500	1.500	2.500	2.000	2.000	2.000	2.000	3.500
Conduit Slop	2.504	5.026	0.206	0.305	0.305	0.305	0.305	0.563	0.266



	006863STMP	004912STMP	006855STMP	014020STMP	004915STMP	014906STMP	014021STMP	006817STMP	006908A
Upstream No	004837IN	004838IN	001535SMH	004845IN	004850IN	004852IN	004008SMH	001538SMH	004794IN
Downstream	004838IN	001535SMH	004845IN	004850IN	004852IN	004008SMH	001538SMH	004794IN	000607ND
Length	13.180	16.912	48.549	173.972	86.416	19.248	11.716	67.441	311.483
Diameter (He	1.250	1.500	1.500	2.500	2.500	2.500	2.500	2.500	3.500
Conduit Slop	2.504	5.028	0.208	0.305	0.305	0.305	0.305	0.563	0.266

Figure 2

Eliminate neck down by increasing diameter of 006873STMP to 5 ft to match next downstream pipe (006942A).



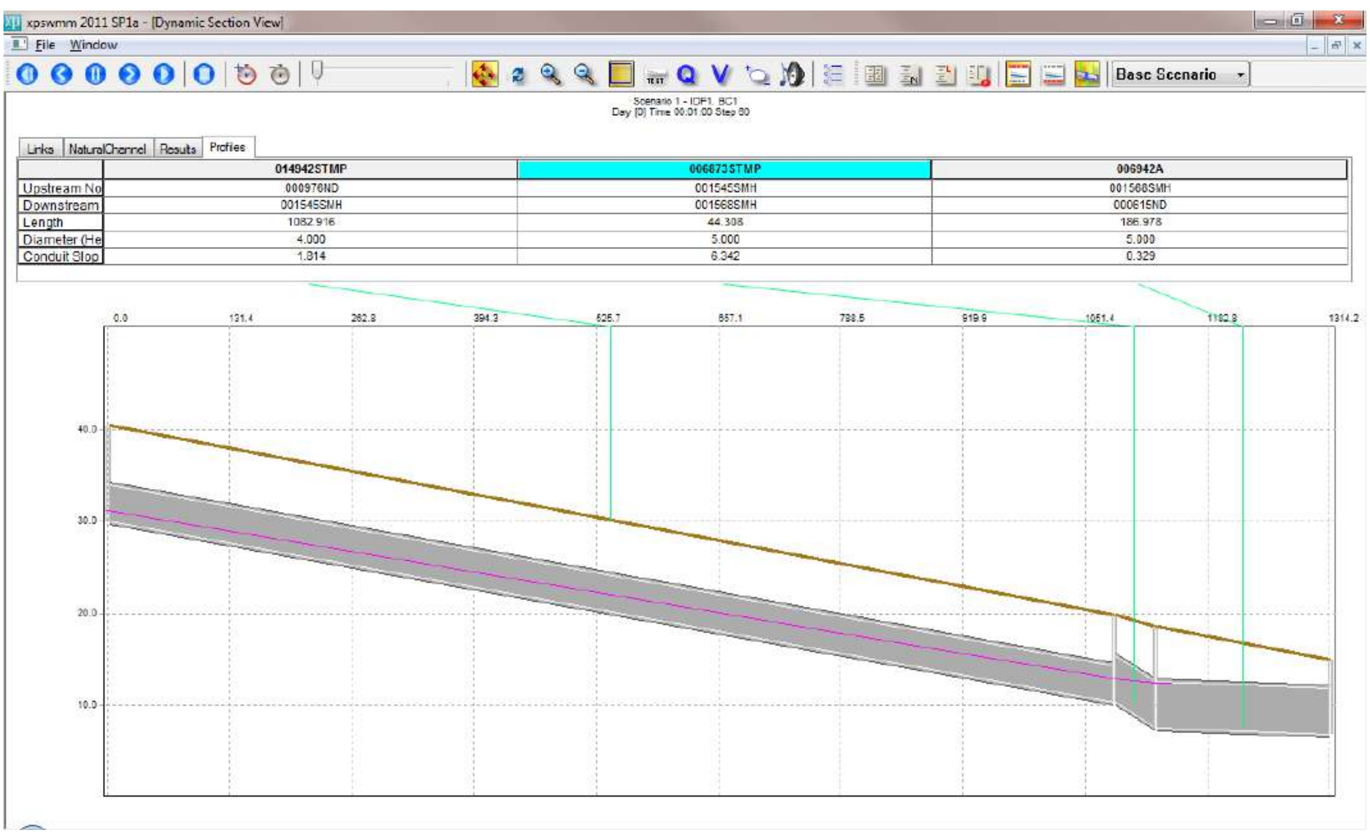
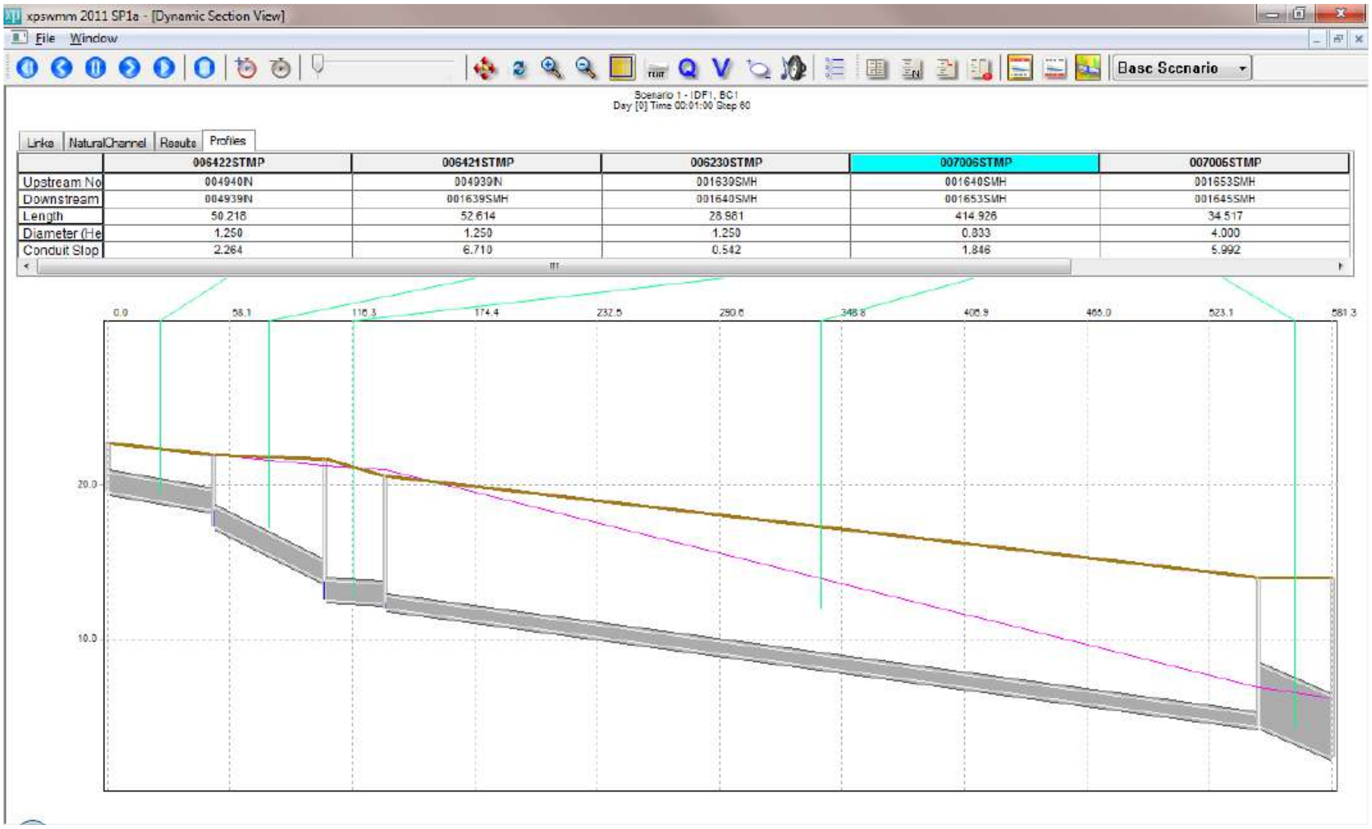
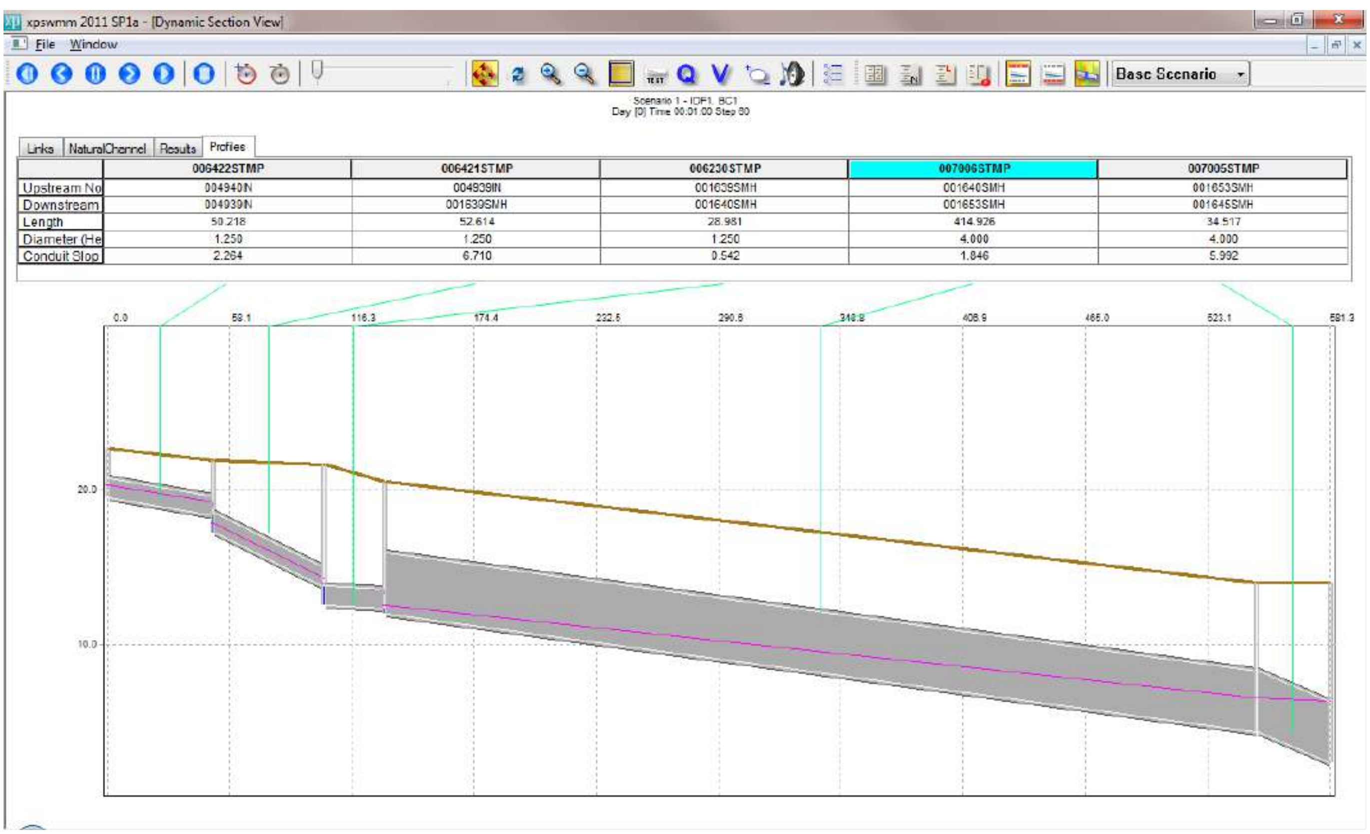


Figure 3

Eliminate neck down by increasing pipe diameter of 007006STMP to 4 ft to match next downstream pipe (007005STMP).



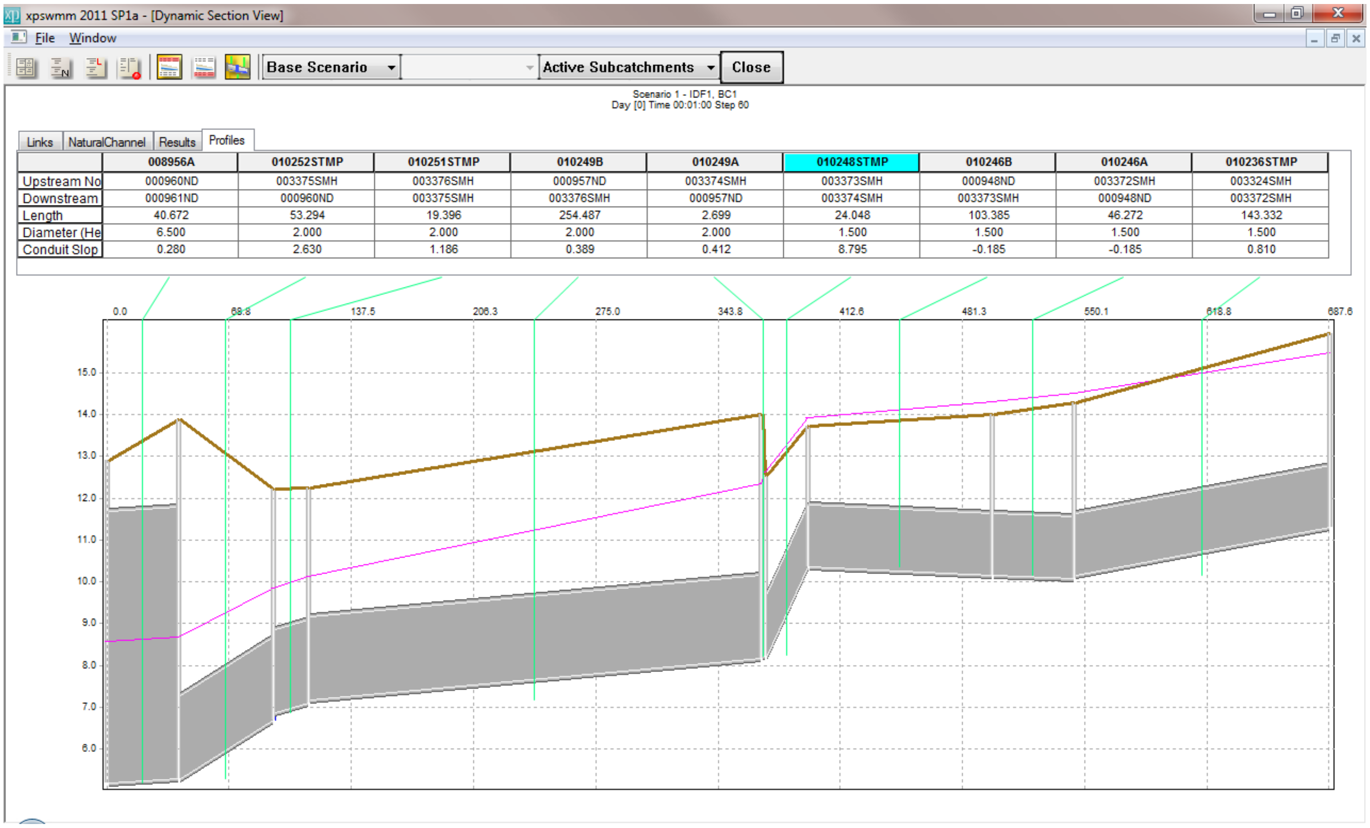
	006422STMP	006421STMP	006230STMP	007006STMP	007005STMP
Upstream No	004940N	004939N	001639SMH	001640SMH	001653SMH
Downstream	004939N	001639SMH	001640SMH	001653SMH	001645SMH
Length	50.218	52.614	28.981	414.926	34.517
Diameter (He	1.250	1.250	1.250	0.833	4.000
Conduit Slop	2.264	6.710	0.542	1.846	5.992



	006422STMP	006421STMP	006230STMP	007006STMP	007005STMP
Upstream No	004940N	004939N	001639SMH	001640SMH	001653SMH
Downstream	004939N	001639SMH	001640SMH	001653SMH	001645SMH
Length	50.218	52.614	28.981	414.926	34.517
Diameter (He	1.250	1.250	1.250	4.000	4.000
Conduit Slop	2.264	6.710	0.542	1.846	5.992

Figure 4

Adjust slope of 010248STMP, 010246B, 010246A to be consistent between next upstream and downstream pipes (010249A and 010236STMP respectively).



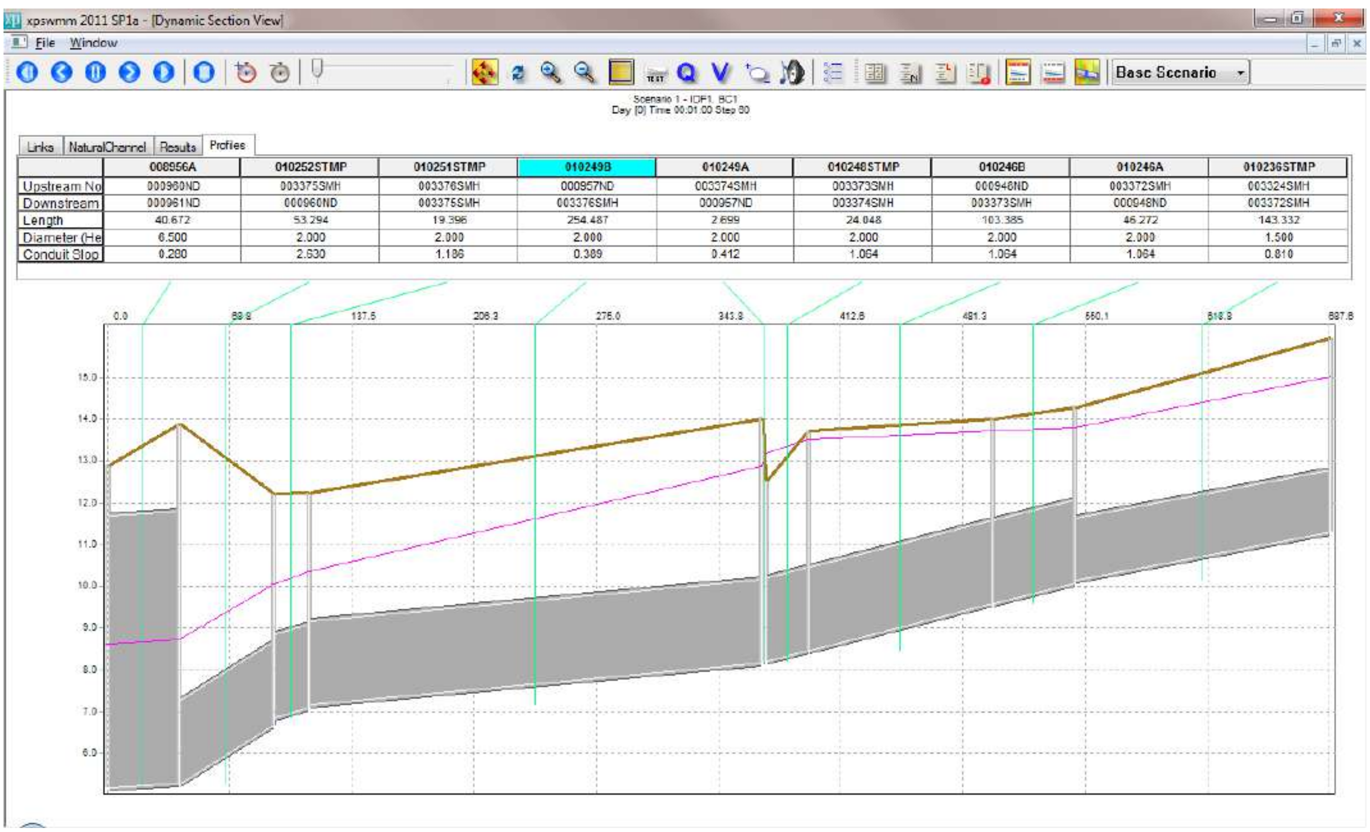
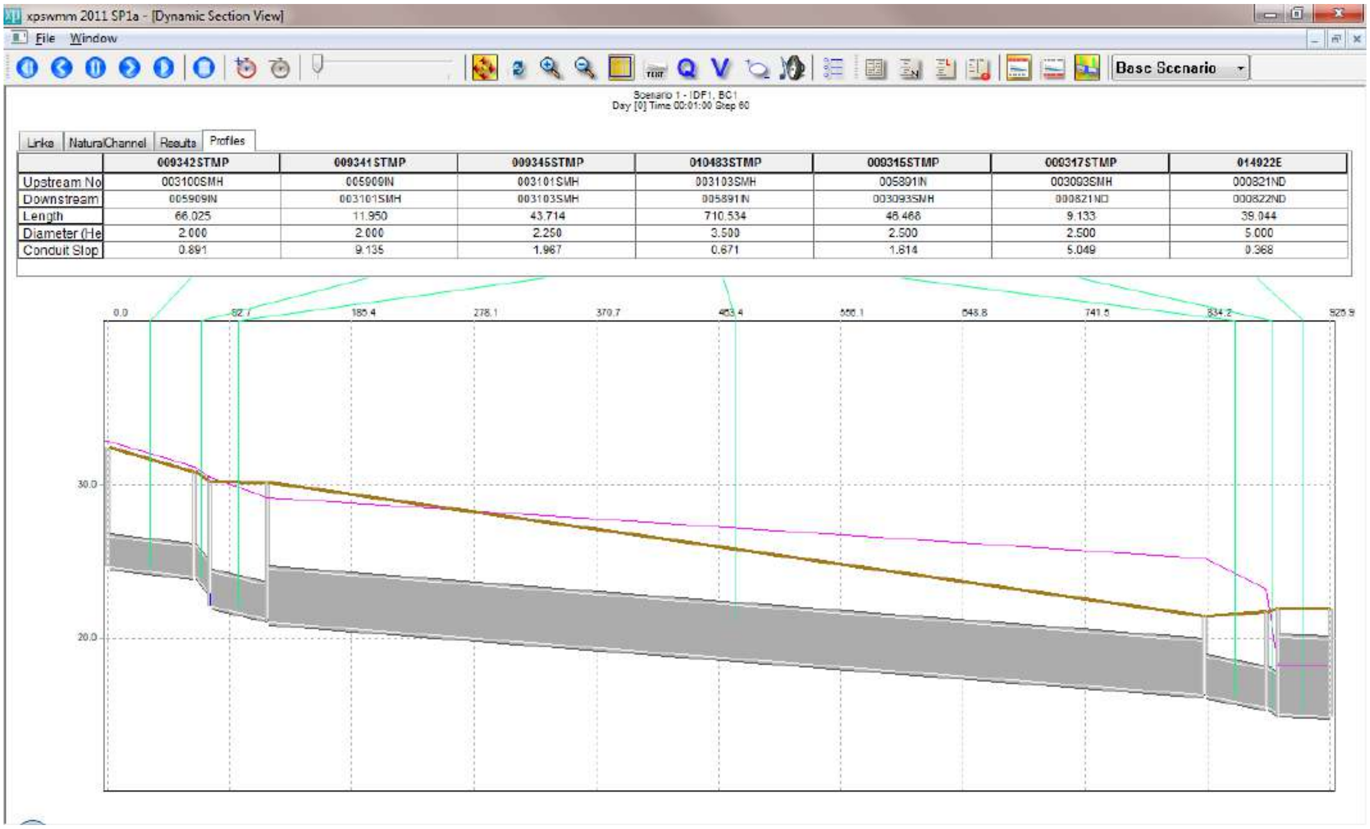


Figure 5

Increase diameter of 009315STMP and 009317STMP to 3.5 ft to match next upstream pipe (010483STMP).



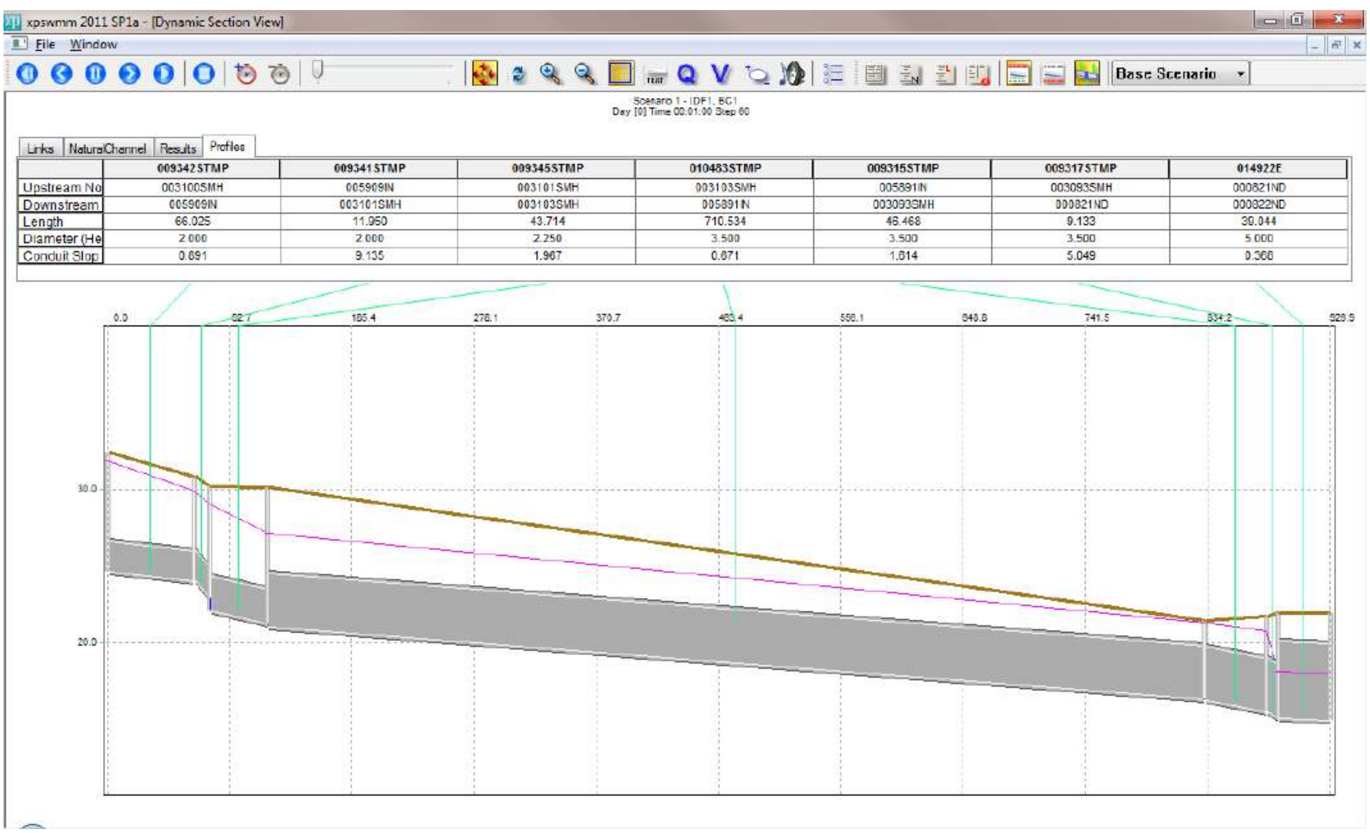
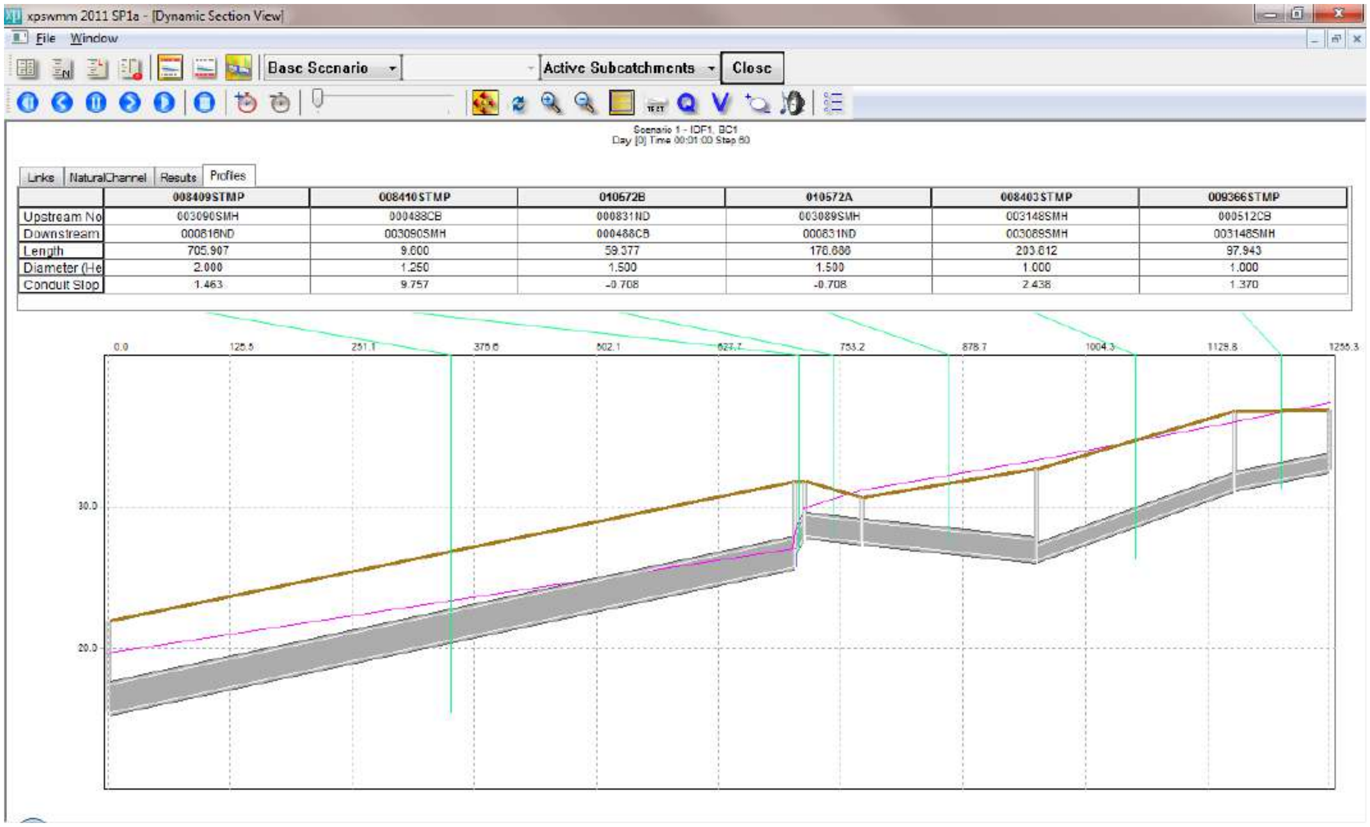


Figure 6

Assume straight line slope between downstream ends of 009366STMP and 008410STMP and increase diameter of 010572A, 010572B, and 008410STMP to 2.0 ft to match next downstream pipe (008409STMP).



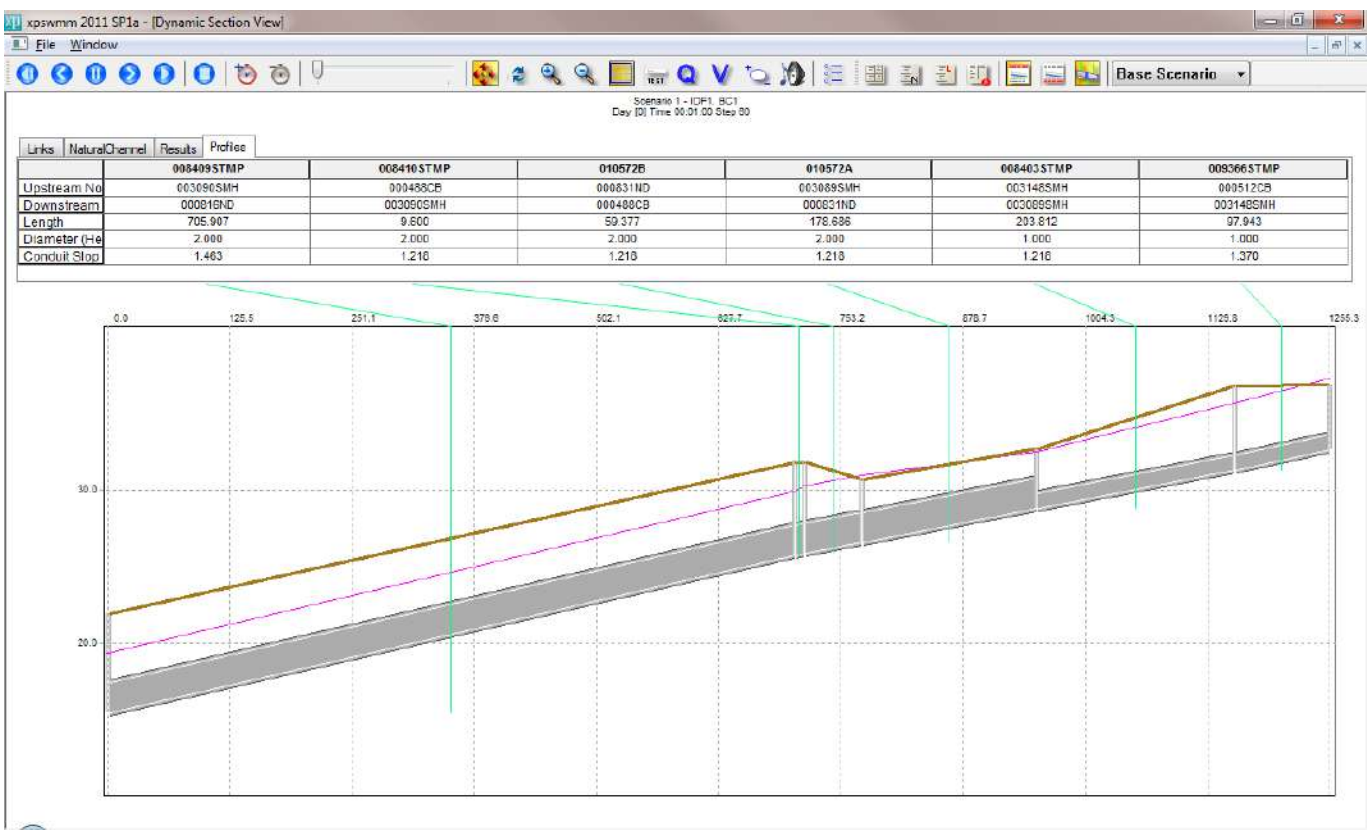
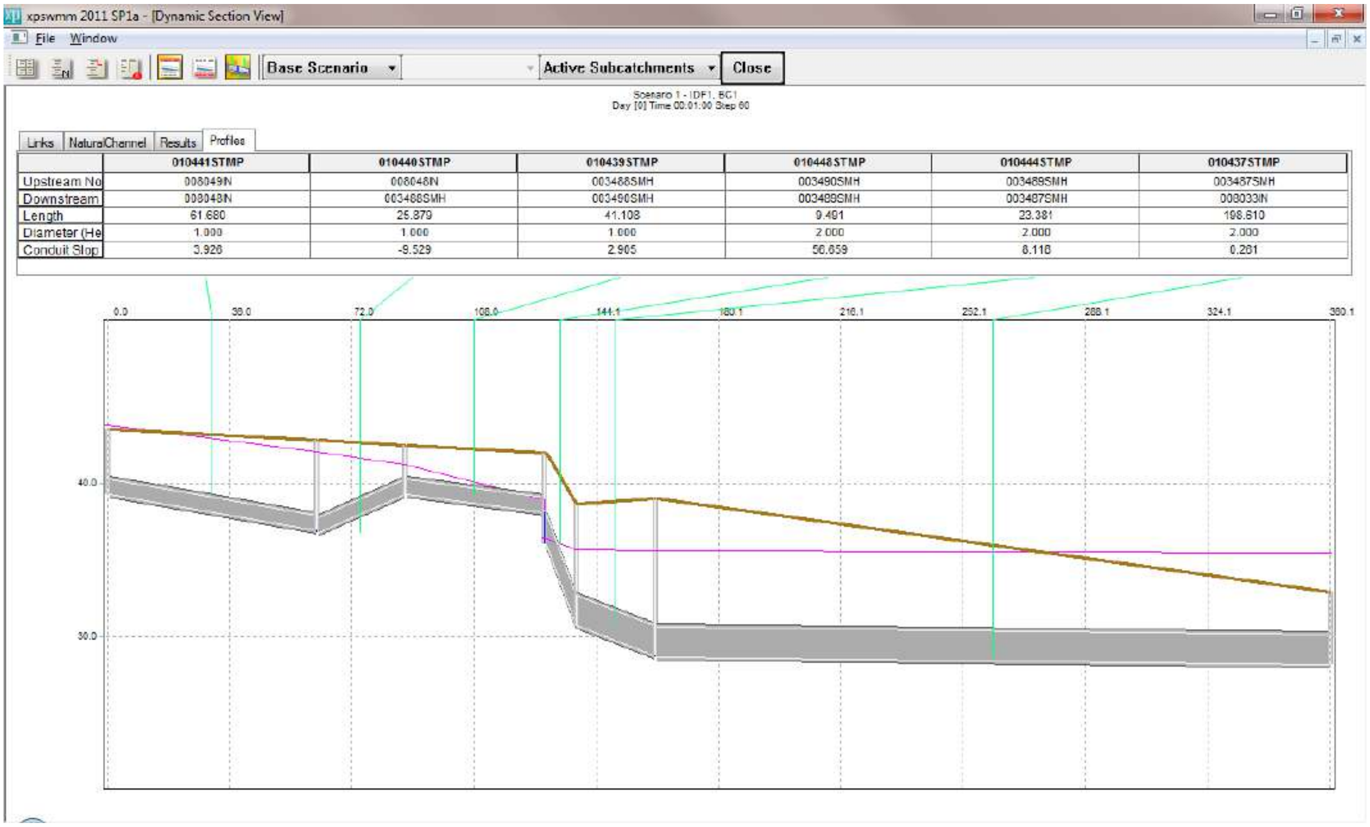
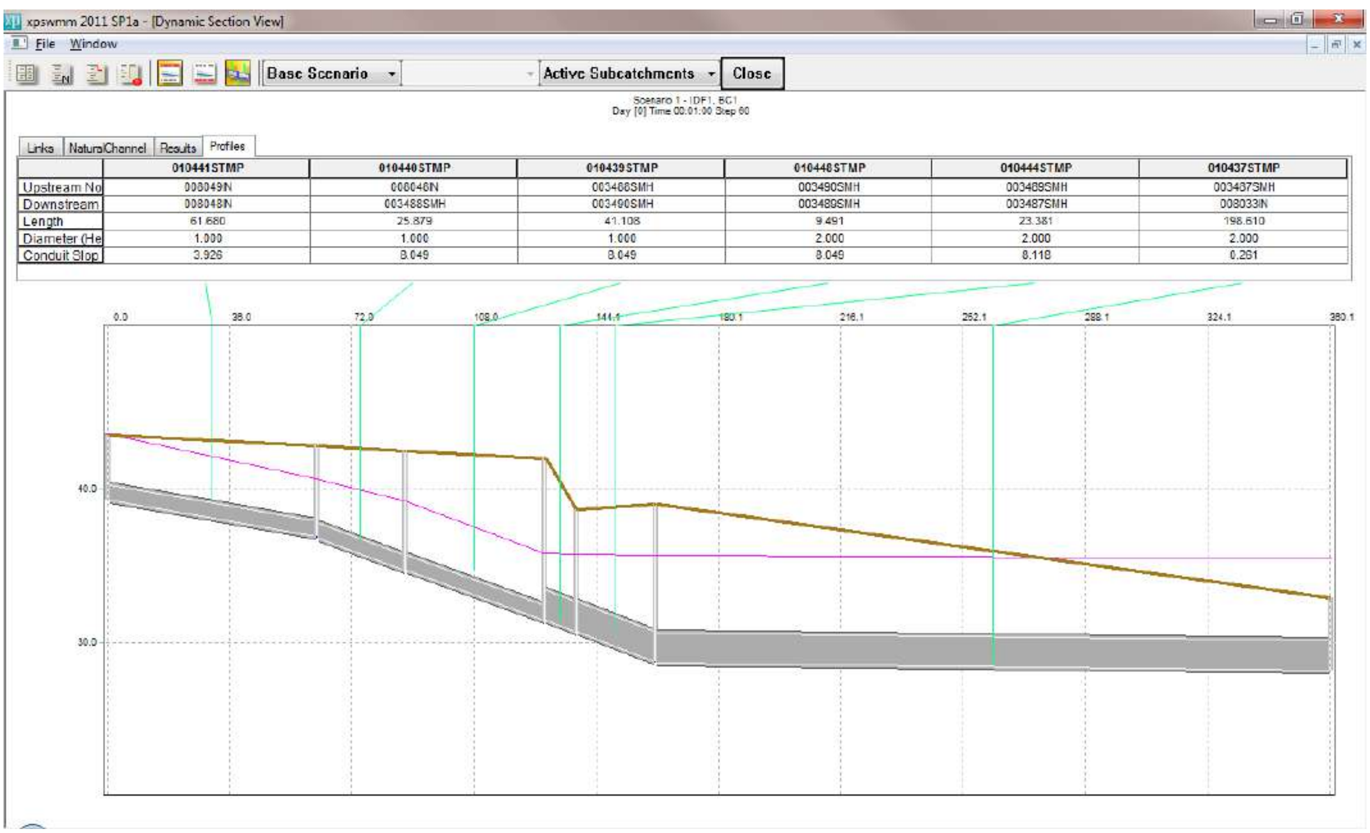


Figure 7

Adjust slope to be constant between 010444STMP and 010441STMP.
NOTE: This area was not surveyed therefore it will be listed as a baseline project, but specifically called out as requiring field verification.



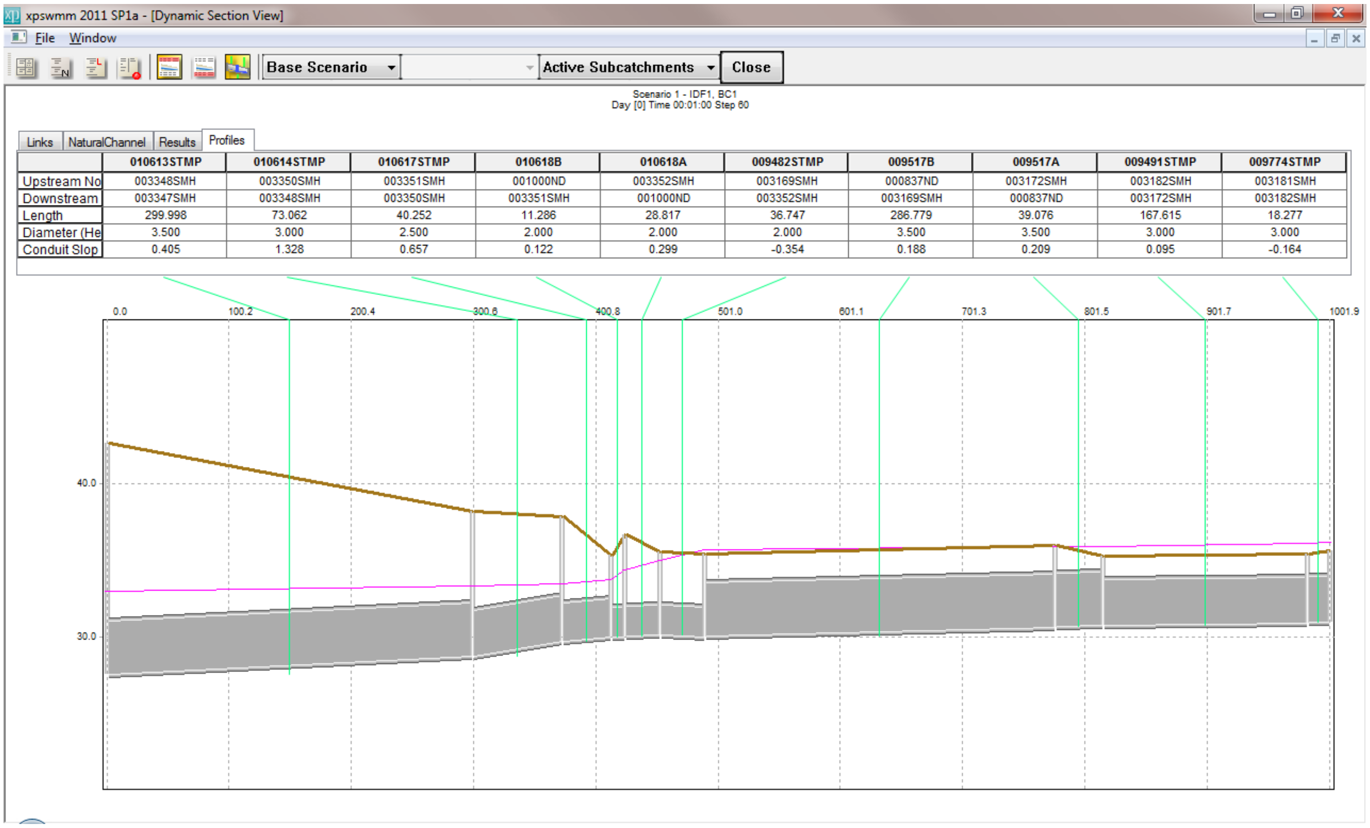
	010441STMP	010440STMP	010439STMP	010448STMP	010444STMP	010437STMP
Upstream No	008049N	008048N	003488SMH	003490SMH	003489SMH	003487SMH
Downstream	008048N	003488SMH	003490SMH	003489SMH	003487SMH	008033N
Length	61.680	25.879	41.108	9.491	23.381	198.610
Diameter (He	1.000	1.000	1.000	2.000	2.000	2.000
Conduit Slop	3.926	-9.529	2.905	50.659	8.118	0.281



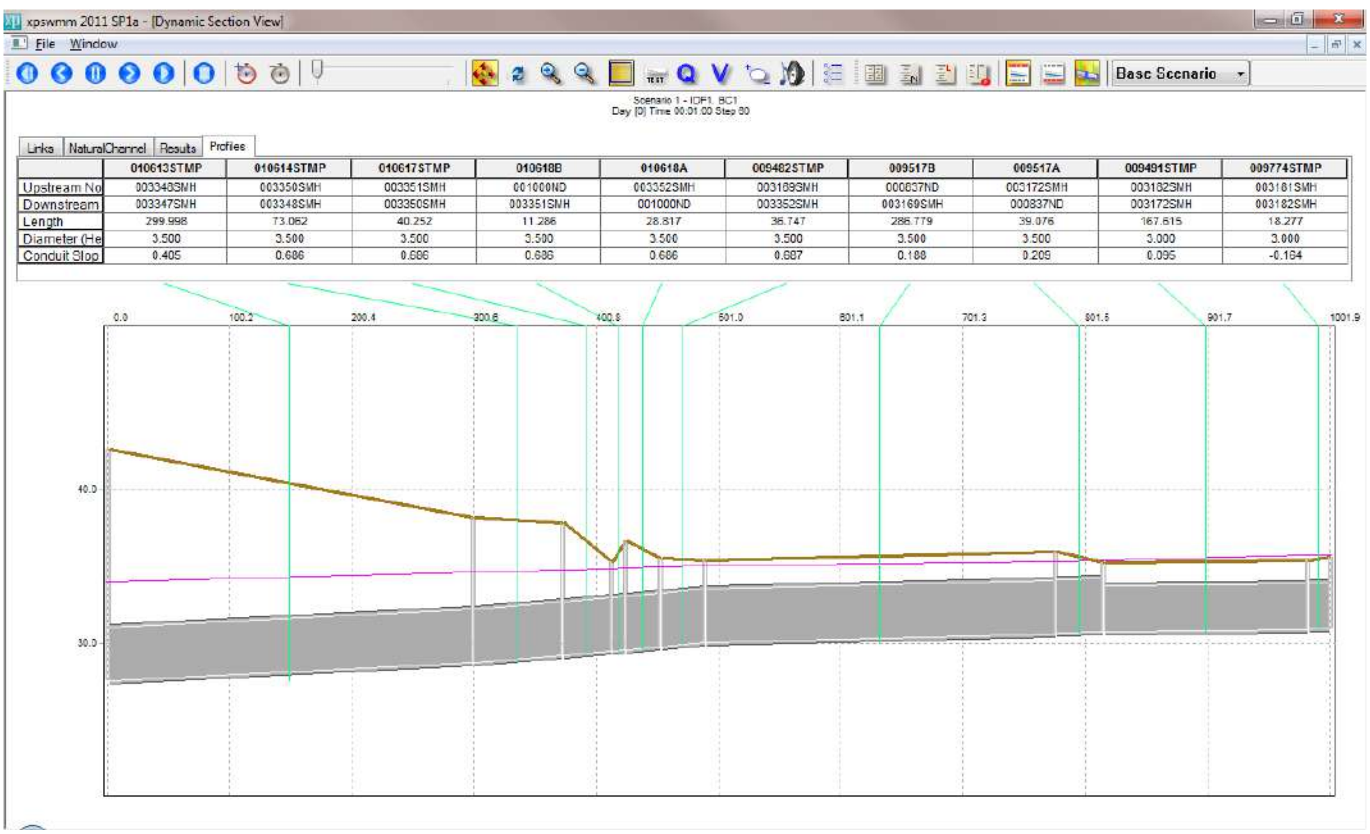
	010441STMP	010440STMP	010439STMP	010448STMP	010444STMP	010437STMP
Upstream No	008049N	008048N	003488SMH	003490SMH	003489SMH	003487SMH
Downstream	008048N	003488SMH	003490SMH	003489SMH	003487SMH	008033N
Length	61.680	25.879	41.108	9.491	23.381	198.610
Diameter (He	1.000	1.000	1.000	2.000	2.000	2.000
Conduit Slop	3.926	8.049	8.049	8.049	8.118	0.281

Figure 8

Increase pipe diameter of 010614STMP, 010617STMP, 010618B, 010618A, and 009482STMP to 3.5 feet to match downstream and upstream pipe diameters (010613STMP and 009517B respectively). Smooth slope between 010613STMP and 009517B (about 0.686%). Adjust size and slope of 009483STMP, located between 009482STMP and 009485STMP (see Figure 12).



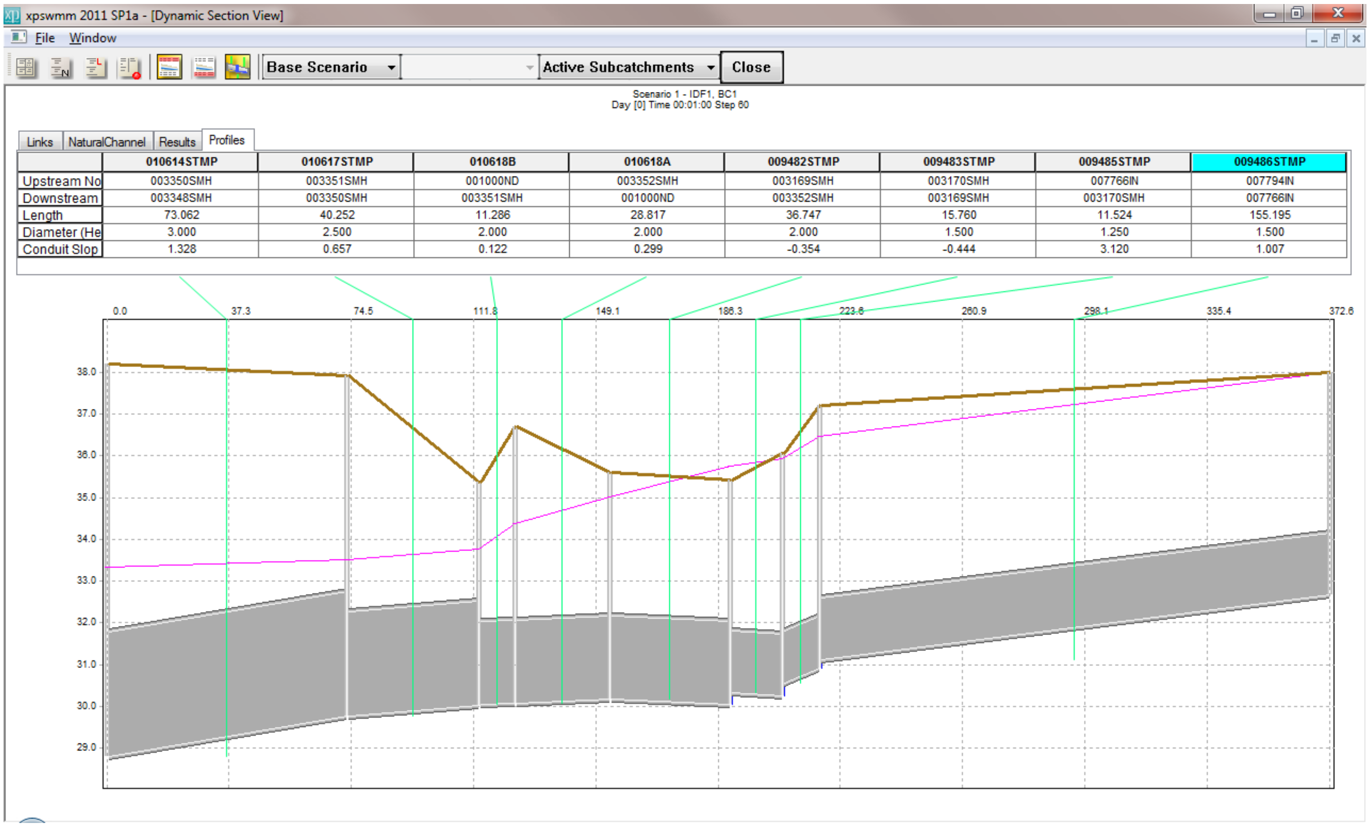
	010613STMP	010614STMP	010617STMP	010618B	010618A	009482STMP	009517B	009517A	009491STMP	009774STMP
Upstream No	003348SMH	003350SMH	003351SMH	001000ND	003352SMH	003169SMH	000837ND	003172SMH	003182SMH	003181SMH
Downstream	003347SMH	003348SMH	003350SMH	003351SMH	001000ND	003352SMH	003169SMH	000837ND	003172SMH	003182SMH
Length	299.998	73.062	40.252	11.286	28.817	36.747	286.779	39.076	167.615	18.277
Diameter (He	3.500	3.000	2.500	2.000	2.000	2.000	3.500	3.500	3.000	3.000
Conduit Slop	0.405	1.328	0.657	0.122	0.299	-0.354	0.188	0.209	0.095	-0.164

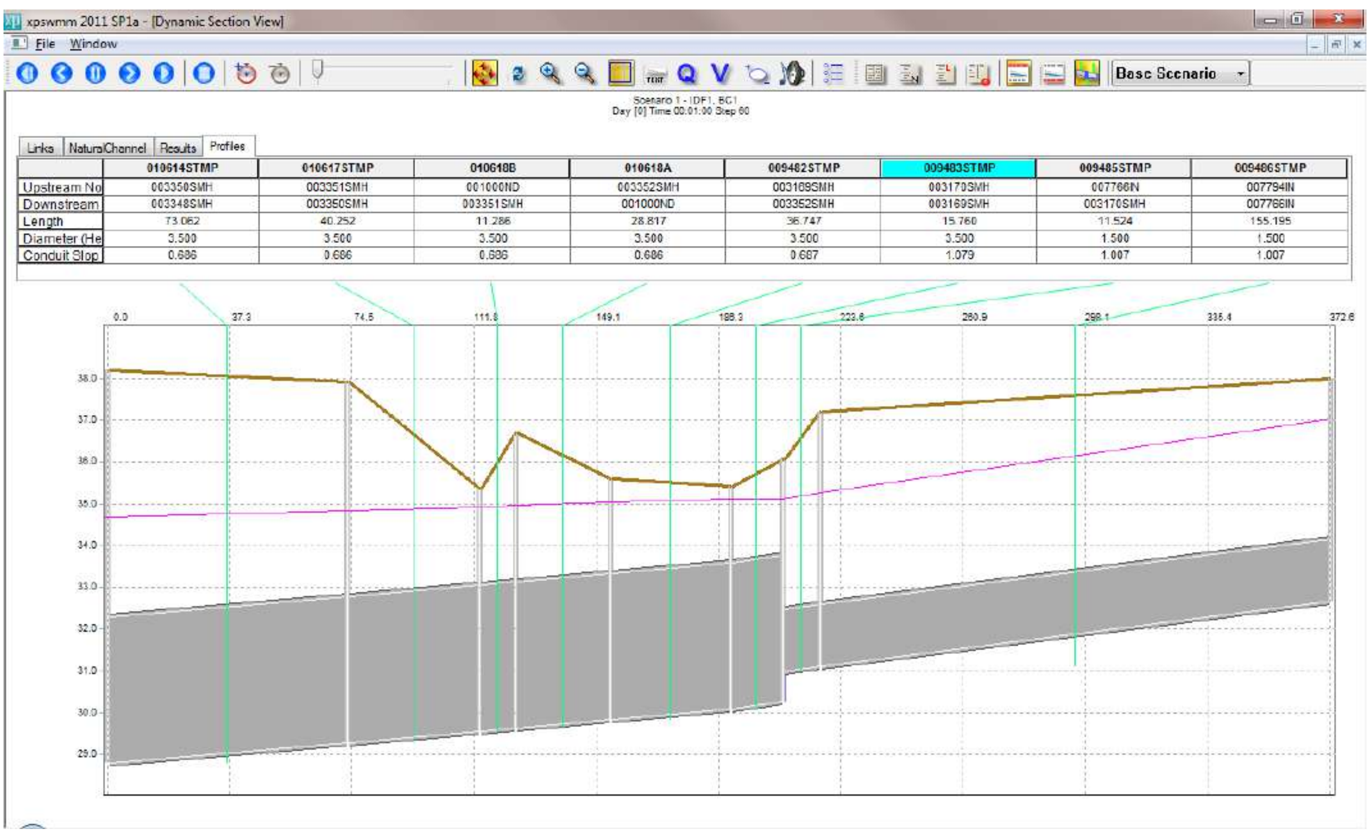


	010613STMP	010614STMP	010617STMP	010618B	010618A	009482STMP	009517B	009517A	009491STMP	009774STMP
Upstream No	003348SMH	003350SMH	003351SMH	001000ND	003352SMH	003169SMH	000837ND	003172SMH	003182SMH	003181SMH
Downstream	003347SMH	003348SMH	003350SMH	003351SMH	001000ND	003352SMH	003169SMH	000837ND	003172SMH	003182SMH
Length	299.998	73.062	40.252	11.286	28.817	36.747	286.779	39.076	167.615	18.277
Diameter (He	3.500	3.500	3.500	3.500	3.500	3.500	3.500	3.500	3.000	3.000
Conduit Slop	0.405	0.686	0.686	0.686	0.686	0.687	0.188	0.209	0.095	-0.164

Figure 9

Increase diameter of 009483STMP to 3.5 ft to match changes downstream (see Figure 11). Adjust slope of 009483STMP to be a straight line between 009483STMP and 009519B (009519B has the lowest invert at manhole 003170SMH). Increase diameter of 009485STMP to match upstream pipe (009486STMP). See Figure 11 for other changes in the area.





Appendix B
Conveyance Solutions

Appendix B - Conveyance Solutions

Summary of 23 Conveyance Solutions developed for Hooffs Run High Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Shape	Existing Diameter/ Height (ft)	Existing Bottom Width (ft)	Proposed Diameter/ Height (ft)	Proposed Bottom Width (ft)	Conduit Slope	Number of Barrels	Roughness
1	009479A	003185SMH	000842ND	28.059	Circular	1.5	0	2.5	0	0.858	1	0.013
1	009479B	000842ND	003184SMH	101.338	Circular	1.5	0	3	0	0.71	1	0.013
1	009491STMP	003182SMH	003172SMH	167.615	Circular	3	0	4	0	0.095	2	0.013
1	009517A	003172SMH	000837ND	39.076	Circular	3.5	0	4	0	0.209	1	0.013
1	009517B	000837ND	003169SMH	286.779	Circular	3.5	0	4.5	0	0.188	1	0.013
1	009518STMP	003183SMH	003173SMH	168.721	Circular	2	0	3	0	0.362	1	0.013
1	009519A	003173SMH	000836ND	25.773	Circular	2	0	3.5	0	0.16	1	0.013
1	009519B	002908ND	003170SMH	131.116	Circular	2	0	4.5	0	0.144	1	0.013
1	009519C	000836ND	002908ND	156.238	Circular	2	0	3.5	0	0.172	1	0.013
1	009557STMP	003190SMH	003185SMH	263.847	Circular	1.25	0	2	0	1.144	1	0.013
1	009566STMP	000853ND	003187SMH	24.139	Circular	2	0	2.5	0	0.207	1	0.013
1	009567STMP	003188SMH	003189SMH	38.729	Circular	2	0	2.5	0	0	2	0.013
1	009570A	003187SMH	000844ND	204.512	Circular	2	0	3	0	0.103	1	0.013
1	009570B	000844ND	003188SMH	9.797	Circular	2	0	2.5	0	0.103	2	0.013
1	009768A	000845ND	003179SMH	132.162	Circular	2	0	3.5	0	0.145	1	0.013
1	009768B	000849ND	000845ND	32.502	Circular	2	0	3	0	0.152	1	0.013
1	009768C	003189SMH	000849ND	111.252	Circular	2	0	3	0	0.152	1	0.013
1	009774STMP	003181SMH	003182SMH	18.277	Circular	3	0	4	0	-0.164	2	0.013
1	009775STMP	003184SMH	003181SMH	45.627	Circular	1.5	0	2.5	0	3.304	1	0.013
1	009786STMP	003193SMH	003041SMH	61.056	Circular	1	0	2	0	0.459	1	0.013
1	010088A	003041SMH	000856ND	21.591	Circular	1	0	2	0	0.459	1	0.013
1	010088B	000856ND	003190SMH	129.6	Circular	1	0	2.5	0	0.382	1	0.013
1	010605STMP	003347SMH	003214SMH	345.508	Circular	3.5	0	6	0	0.136	1	0.013
1	010613STMP	003348SMH	003347SMH	299.998	Circular	3.5	0	5	0	0.405	1	0.013
1	010614STMP	003350SMH	003348SMH	73.062	Circular	3.5	0	4	0	1.328	1	0.013
1	010617STMP	003351SMH	003350SMH	40.252	Circular	3.5	0	4.5	0	0.657	1	0.013
1	010618A	003352SMH	001000ND	28.817	Circular	3.5	0	5.5	0	0.299	1	0.013
1	010618B	001000ND	003351SMH	11.286	Circular	3.5	0	4.5	0	0.122	2	0.013
1	014039A	007779IN	000839ND	55.666	Circular	2	0	3.5	0	-0.102	2	0.013
1	014039B	000839ND	003183SMH	151.043	Circular	2	0	4	0	-0.102	1	0.013
2	008644A	006172IN	000847ND	74.32	Circular	2	0	3	0	0.288	1	0.013
2	008644B	000847ND	003383SMH	162.131	Circular	2	0	3	0	0.288	1	0.013
2	008976A	003384SMH	000846ND	32.87	Circular	2	0	3.5	0	0.173	1	0.021
2	008976B	000846ND	004007SMH	215.187	Circular	2	0	3.5	0	0.164	1	0.021
2	008978A	003385SMH	000833ND	130.786	Circular	1	0	3	0	0.548	1	0.021
2	008978B	000833ND	003384SMH	14.775	Circular	1	0	3	0	0.548	2	0.021
2	009705STMP	003430SMH	000974ND	70.566	Circular	0.833	0	1.5	0	5.014	1	0.011
2	009706STMP	000974ND	003428SMH	92.508	Circular	0.833	0	1.5	0	4.474	1	0.013
2	009737A	003383SMH	000832ND	66.959	Circular	2	0	3	0	0.314	1	0.021
2	009737B	000832ND	003384SMH	22.078	Circular	2	0	3	0	0.314	1	0.021
2	009847STMP	003394SMH	003385SMH	126.627	Circular	1.25	0	3	0	0.565	1	0.013
2	010286STMP	003428SMH	003394SMH	47.392	Circular	1.25	0	3	0	0.24	1	0.013

Appendix B - Conveyance Solutions

Summary of 23 Conveyance Solutions developed for Hooffs Run High Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Shape	Existing Diameter/ Height (ft)	Existing Bottom Width (ft)	Proposed Diameter/ Height (ft)	Proposed Bottom Width (ft)	Conduit Slope	Number of Barrels	Roughness
2	010292STMP	004007SMH	003388SMH	232.838	Circular	2	0	3	0	0.163	1	0.013
3	008527STMP	003462SMH	003456SMH	22.256	Circular	3	0	4	0	8.133	1	0.013
3	008530STMP	003463SMH	003462SMH	65.798	Circular	3	0	6	0	0.714	1	0.013
3	008531STMP	008004IN	003463SMH	78.311	Rectangular	3	0	4	7	0.409	1	0.013
3	008534A	003465SMH	0001033ND	383.314	Rectangular	2	0	3	6	0.644	1	0.013
3	008534B	0001033ND	003440SMH	31.17	Rectangular	2	0	3	6	0.58	1	0.013
3	009968STMP	008019IN	0001037ND	22.112	Circular	2	0	2.5	0	1.137	1	0.013
3	010058A	003472SMH	0001038ND	128.923	Circular	2	0	3.5	0	0.524	2	0.013
3	010058B	0001038ND	003465SMH	69.598	Circular	2	0	3.5	0	0.509	2	0.013
3	010430STMP	003483SMH	003472SMH	151.684	Circular	1.25	0	2.5	0	0.776	1	0.013
3	010460STMP	003470SMH	008019IN	118.532	Circular	2	0	3	0	0.827	1	0.013
3	010465B	0001037ND	0001036ND	67.341	Circular	2	0	3	0	1.137	1	0.013
3	010465C	0001036ND	0001035ND	213.811	Circular	2	0	3	0	1.137	1	0.013
3	010465D	0001035ND	003468SMH	91.605	Circular	2	0	3	0	1.137	1	0.013
3	010467STMP	003471SMH	003470SMH	115.375	Circular	2	0	3	0	0.269	1	0.013
3	010635STMP	003440SMH	003448SMH	30.005	Rectangular	2	0	3	6	0.533	1	0.013
3	010636STMP	003448SMH	003368SMH	101.661	Rectangular	2	0	3	7	0.59	1	0.013
3	014018STMP	003368SMH	008004IN	61.072	Rectangular	2.5	0	4	7	0.246	1	0.013
4	010036STMP	003421SMH	003418SMH	225.469	Rectangular	4	7	4	12	0.257	1	0.013
4	010037STMP	001968SMH	003421SMH	78.072	Rectangular	4	7	4	12	-0.242	1	0.013
4	011383A	001970SMH	001151ND	98.714	Circular	3	0	7.5	0	0.805	1	0.013
4	011383B	001151ND	001969SMH	19.338	Circular	3	0	7.5	0	0.598	1	0.013
4	011390A	001974SMH	001137ND	43.751	Circular	2	0	5	0	0.559	1	0.013
4	011390B	001137ND	001970SMH	126.321	Circular	2	0	6.5	0	0.171	1	0.013
4	011391STMP	001971SMH	001970SMH	33.224	Circular	3	0	4.5	0	5.027	1	0.013
4	011392A	001973SMH	001135ND	8.345	Circular	2	0	3	0	0.363	1	0.013
4	011392B	001135ND	001944SMH	261.82	Circular	2	0	4	0	0.363	1	0.013
4	011441STMP	006540IN	001962SMH	203.816	Circular	2	0	4.5	0	0.493	1	0.013
4	011442STMP	001944SMH	001943SMH	237.193	Circular	1.75	0	3.5	0	0.788	1	0.013
4	011443STMP	001962SMH	006548IN	51.56	Circular	2.5	0	5	0	-0.247	1	0.013
4	011444A	006548IN	001131ND	275.922	Circular	2.5	0	4.5	0	0.382	1	0.013
4	011444B	001131ND	001963SMH	27.411	Circular	2.5	0	4	0	0.236	2	0.013
4	011447STMP	001963SMH	001965SMH	194.813	Circular	2.5	0	4	0	0.164	2	0.013
4	011450STMP	001966SMH	001965SMH	138.727	Circular	3	0	7.5	0	0.75	1	0.013
4	011451STMP	001965SMH	001968SMH	127.048	Rectangular	4	0	4	12	0.463	1	0.013
4	011452STMP	001967SMH	001966SMH	48.863	Circular	3	0	8	0	0.491	1	0.013
4	011453STMP	001969SMH	001967SMH	255.313	Circular	3	0	8	0	0.321	1	0.013
4	011632A	001988SMH	001136ND	275.407	Circular	2	0	5	0	0.415	1	0.013
4	011632B	001136ND	001974SMH	52.619	Circular	2	0	5.5	0	0.396	1	0.013
4	011675STMP	006639IN	002016SMH	4.714	Circular	2	2	2.5	2	0.212	2	0.013
4	011676STMP	002016SMH	002017SMH	81.373	Circular	2	0	2.5	0	0.283	2	0.013
4	012049STMP	002018SMH	001971SMH	451.539	Circular	3	0	5	0	2.629	1	0.013

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Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Shape	Existing Diameter/ Height (ft)	Existing Bottom Width (ft)	Proposed Diameter/ Height (ft)	Proposed Bottom Width (ft)	Conduit Slope	Number of Barrels	Roughness
4	012188STMP	001943SMH	006540IN	40.692	Circular	1.75	0	5	0	-0.168	1	0.013
4	012193A	001983SMH	001134ND	260.705	Circular	1.75	0	2.5	0	0.896	1	0.013
4	012193B	001134ND	001973SMH	15.417	Circular	1.75	0	3.5	0	0.247	1	0.013
4	012262A	002022SMH	001148ND	36.978	Circular	2	0	4.5	0	0.685	1	0.013
4	012262B	001148ND	001988SMH	19.95	Circular	2	0	5	0	0.535	1	0.013
5	007718C	000926ND	003262SMH	34.869	Circular	1.5	0	2	0	2.056	1	0.013
5	009011STMP	003262SMH	003293SMH	176.896	Circular	2	0	2.75	0	0.543	1	0.013
5	009623STMP	003263SMH	003273SMH	6.276	Circular	2	0	2.5	0	1.753	1	0.013
5	009910A	003274SMH	000929ND	46.499	Circular	2.5	0	5.5	0	0.777	1	0.013
5	009910B	000929ND	003278SMH	140.019	Circular	2.5	0	5.5	0	0.735	1	0.013
5	010168STMP	003273SMH	003264SMH	150.421	Circular	2	0	4	0	2.466	1	0.013
5	010169STMP	003264SMH	003274SMH	109.485	Circular	1.75	0	4	0	2.685	1	0.013
5	010176A	003278SMH	000938ND	31.103	Circular	2.5	0	5.5	0	0.757	1	0.013
5	010176B	000938ND	003301SMH	40.256	Circular	2.5	0	5.5	0	0.707	1	0.013
5	010195STMP	003301SMH	003310SMH	23.279	Circular	2.5	0	5	0	-0.859	1	0.013
5	010196STMP	003310SMH	003311SMH	87.48	Circular	2.5	0	5.5	0	0.674	1	0.013
5	010197STMP	003311SMH	003312SMH	113.225	Circular	2.5	0	5	0	1.051	1	0.013
5	010199STMP	003312SMH	000959ND	45.513	Circular	2.5	0	5	0	1.329	1	0.013
6	009817STMP	001908SMH	001909SMH	266.255	Circular	2	0	4.5	0	0.361	1	0.013
6	009865STMP	001909SMH	003446SMH	23.272	Circular	2.25	0	6.5	0	0.043	1	0.013
6	009866STMP	003446SMH	003447SMH	100.781	Circular	2.25	0	4.5	0	0.387	1	0.013
6	009867STMP	003447SMH	003051SMH	54.892	Circular	2.25	0	4.5	0	0.401	1	0.013
6	009869A	003051SMH	000802ND	374.461	Circular	2.25	0	4.5	0	0.16	2	0.013
6	009869B	000802ND	003339SMH	6.488	Circular	2.25	0	4.5	0	0.16	2	0.013
6	010302STMP	003336SMH	003335SMH	7.17	Circular	2.25	0	3	0	-14.923	1	0.013
6	010303STMP	003337SMH	003336SMH	38.682	Circular	2.25	0	3.5	0	4.11	1	0.013
6	010331STMP	001992SMH	003339SMH	144.599	Circular	2.25	0	4	0	0.609	1	0.013
6	010332STMP	003339SMH	003337SMH	296.022	Circular	2.25	0	3.75	0	0.642	2	0.013
6	011123STMP	001904SMH	001906SMH	268.666	Circular	1.75	0	3	0	0.674	1	0.013
6	011124STMP	001905SMH	001904SMH	22.708	Circular	1.75	0	3.5	0	0.255	1	0.013
6	011130STMP	001906SMH	001908SMH	17.185	Circular	2	0	3	0	0.582	1	0.013
6	011535STMP	001942SMH	001992SMH	158.332	Circular	2	0	3.5	0	0.783	1	0.013
6	011633STMP	001961SMH	001942SMH	244.736	Circular	2	0	4	0	0.552	1	0.013
6	011634STMP	001975SMH	001947SMH	262.509	Circular	2	0	3.5	0	0.587	1	0.013
6	011635STMP	001981SMH	001975SMH	250.929	Circular	2	0	2.5	0	0.586	1	0.013
6	011638STMP	006587IN	001982SMH	39.167	Circular	2	0	3	0	0.434	1	0.013
6	014005STMP	001947SMH	001961SMH	30.188	Circular	2	0	3.5	0	1.027	1	0.013
7	007707A	002646SMH	000735ND	80.889	Circular	1.75	0	4	0	0.493	1	0.013
7	007707B	000735ND	000736ND	305.953	Circular	1.75	0	4	0	0.493	1	0.013
7	007707C	000736ND	002647SMH	56.442	Circular	1.75	0	4	0	0.227	2	0.013
7	008450STMP	003035SMH	003034SMH	53.472	Circular	1.75	0	3	0	7.108	1	0.013
7	008451STMP	003036SMH	003035SMH	104.511	Circular	1.75	0	3.4	0	0.457	1	0.013

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Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Shape	Existing Diameter/ Height (ft)	Existing Bottom Width (ft)	Proposed Diameter/ Height (ft)	Proposed Bottom Width (ft)	Conduit Slope	Number of Barrels	Roughness
7	008452A	003034SMH	000750ND	102.099	Circular	1.75	0	4	0	0.85	1	0.013
7	008452B	000750ND	003039SMH	507.926	Circular	1.75	0	4.5	0	0.839	1	0.013
7	009203A	002647SMH	000734ND	43.964	Circular	1.75	0	4	0	0.811	1	0.013
7	009203B	000754ND	000753ND	21.734	Circular	1.75	0	4	0	0.811	1	0.013
7	009203C	000753ND	003036SMH	273.887	Circular	1.75	0	4	0	0.782	1	0.013
7	009203D	000734ND	000754ND	195.234	Circular	1.75	0	4	0	0.811	1	0.013
7	009402A	002643SMH	000732ND	87.119	Circular	1.5	0	3.5	0	0.957	1	0.013
7	009402B	000733ND	002646SMH	46.553	Circular	1.5	0	3.5	0	0.527	1	0.013
7	009402C	000732ND	000726ND	119.91	Circular	1.5	0	3.5	0	0.957	1	0.013
7	009402D	000726ND	000733ND	135.647	Circular	1.5	0	3.5	0	0.957	1	0.013
7	009404A	000731ND	000724ND	111.713	Circular	1.5	0	3	0	0.438	1	0.013
7	009404B	000724ND	002643SMH	127.174	Circular	1.5	0	3	0	0.202	1	0.013
7	009415STMP	002644SMH	002645SMH	182.391	Circular	1.25	0	2	0	0.594	1	0.013
7	009417STMP	002645SMH	000731ND	139.699	Circular	1.25	0	2.5	0	0.438	1	0.013
8	008706C	000949ND	003406SMH	173.013	Rectangular	5	5	4	8	-0.024	1	0.013
8	009494A	003413SMH	000955ND	86.318	Circular	1.75	0	2	0	0.827	1	0.013
8	009494B	000955ND	003412SMH	102.884	Circular	1.75	0	3	0	0.827	1	0.013
8	009499STMP	003414SMH	003416SMH	70.057	Circular	2	0	3.5	0	0.457	2	0.013
8	009504A	003416SMH	000956ND	62.568	Circular	2	0	3.5	0	0.104	2	0.013
8	009504B	000956ND	003417SMH	33.163	Circular	2	0	3.5	0	0.104	2	0.013
8	009508STMP	003417SMH	000966ND	23.673	Circular	2	0	3.5	0	1.813	1	0.013
8	009510STMP	003419SMH	006189IN	4.465	Circular	2	0	2.5	0	-7.321	1	0.013
8	009580A	003406SMH	002914ND	173.996	Rectangular	4	7	4	12	0.354	1	0.013
8	009580C	002914ND	003402SMH	40.005	Rectangular	4	7	4	12	0.399	1	0.013
8	009688A	003412SMH	000954ND	19.222	Rectangular	4	7	4	12	0.062	1	0.013
8	009688B	000954ND	000936ND	136.889	Rectangular	4	7	4	12	0.062	1	0.013
8	009688C	000936ND	003406SMH	22.123	Rectangular	4	7	4	12	0.062	1	0.013
8	009689STMP	000587CB	003413SMH	36.482	Circular	1.25	0	3	0	-0.072	1	0.013
8	010034A	003418SMH	000966ND	25.804	Rectangular	4	7	4	12	0.269	1	0.013
8	010034B	000966ND	003412SMH	167.82	Rectangular	4	7	4	12	0.269	1	0.013
8	010046A	003423SMH	000968ND	53.886	Circular	2	0	3.5	0	0.582	1	0.013
8	010046B	000968ND	003419SMH	207.352	Circular	2	0	3.5	0	0.577	1	0.013
8	010048STMP	003410SMH	003423SMH	205.889	Circular	1.25	0	2.5	0	1.009	1	0.013
9	009076STMP	003071SMH	003084SMH	228.12	Circular	2	0	3	0	0.793	1	0.013
9	009286STMP	003083SMH	003082SMH	27.906	Circular	2	0	3	0	2.365	1	0.013
9	009287STMP	003082SMH	005833IN	44.473	Circular	2	0	4	0	0.317	1	0.013
9	009289STMP	003085SMH	003083SMH	8.593	Circular	1.5	0	2	0	9.144	1	0.013
9	009290A	003086SMH	000767ND	49.75	Circular	1.5	0	2	0	9.243	1	0.013
9	009290B	000767ND	003085SMH	34.832	Circular	1.5	0	2	0	9.099	1	0.013
10	008324STMP	003163SMH	003107SMH	195.627	Circular	2	0	3	0	1.252	1	0.013
10	008327STMP	003168SMH	000493CB	225.205	Circular	1.25	0	3.5	0	0.186	1	0.013
10	009338STMP	003098SMH	003099SMH	14.791	Circular	2.25	0	3	0	1.285	1	0.013

Appendix B - Conveyance Solutions

Summary of 23 Conveyance Solutions developed for Hooffs Run High Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Shape	Existing Diameter/ Height (ft)	Existing Bottom Width (ft)	Proposed Diameter/ Height (ft)	Proposed Bottom Width (ft)	Conduit Slope	Number of Barrels	Roughness
10	009341STMP	005909IN	003101SMH	11.95	Circular	2	0	3	0	9.135	1	0.013
10	009342STMP	003100SMH	005909IN	66.025	Circular	2	0	4.5	0	0.891	1	0.013
10	009343STMP	003160SMH	003100SMH	170.306	Circular	2	0	3.5	0	2.519	1	0.013
10	009345STMP	003101SMH	003103SMH	43.714	Circular	2.25	0	4.5	0	1.967	1	0.013
10	009346A	003099SMH	000768ND	211.698	Circular	2.25	0	3.5	0	0.774	1	0.013
10	009346B	000768ND	003101SMH	95.846	Circular	2.25	0	3.5	0	0.774	1	0.013
10	009348STMP	003102SMH	003103SMH	35.178	Circular	2	0	3	0	2.558	1	0.013
10	009362STMP	003107SMH	003108SMH	98.494	Circular	2	0	4	0	0.68	1	0.013
10	010075STMP	000493CB	003163SMH	81.034	Circular	1.5	0	2	0	3.778	1	0.013
10	010480STMP	003167SMH	003160SMH	167.764	Circular	2	0	3.5	0	3.374	1	0.013
10	010484A	003108SMH	000794ND	172.043	Circular	2	0	3.5	0	1.142	1	0.013
10	010484B	000794ND	003102SMH	19.659	Circular	2	0	3.5	0	0.837	1	0.013
11	008355STMP	003120SMH	003122SMH	203.444	Circular	2.5	0	4.5	0	1.199	1	0.013
11	009813STMP	003360SMH	003364SMH	28.975	Circular	2	0	4	0	0.518	1	0.013
11	009958A	003427SMH	000995ND	317.109	Circular	1.5	0	2.5	0	3.544	1	0.013
11	009958B	000995ND	003212SMH	18.634	Circular	1.5	0	2.5	0	3.061	1	0.013
11	010405STMP	003364SMH	003365SMH	107.519	Circular	2	0	3	0	2.595	1	0.013
11	010408A	003366SMH	001013ND	194.748	Circular	3	0	4	0	1.991	1	0.013
11	010408B	001013ND	003120SMH	302.873	Circular	3	0	4	0	1.869	1	0.013
11	010410A	003212SMH	001010ND	287.349	Circular	1.75	0	3	0	2.156	1	0.013
11	010410B	001010ND	003360SMH	72.441	Circular	1.75	0	3	0	2.156	1	0.013
12	006225STMP	001636SMH	001611SMH	145.903	Circular	1.5	0	3	0	1.186	1	0.013
12	006226STMP	001637SMH	001636SMH	63.953	Circular	1.5	0	3	0	0.268	1	0.013
12	006228STMP	001638SMH	001637SMH	75.761	Circular	1.5	0	2.5	0	2.046	1	0.013
12	006232STMP	001611SMH	001633SMH	124.722	Circular	1.5	0	2.5	0	1.88	1	0.013
12	006234STMP	001633SMH	001609SMH	92.747	Circular	1.5	0	3	0	2.182	1	0.013
12	006498STMP	001609SMH	001635SMH	95.399	Circular	2	0	3.3	0	0.121	1	0.013
13	008791STMP	002608SMH	002606SMH	252.396	Circular	3.5	0	4.5	0	1.208	2	0.013
13	009064STMP	002538SMH	005541IN	41.139	Circular	2.5	0	4.5	0	1.247	1	0.013
13	009070STMP	002541SMH	000697ND	56.386	Circular	2	0	2.5	0	3.398	1	0.013
13	009382STMP	002544SMH	002608SMH	124.601	Circular	3.5	0	4.5	0	1.348	2	0.013
13	009387STMP	007610IN	002544SMH	33.098	Circular	2.5	0	4	0	5.166	1	0.013
13	009388STMP	005541IN	007610IN	625.16	Circular	2.5	0	4	0	2.581	1	0.013
13	014918STMP	000697ND	002538SMH	8.889	Circular	3	0	6.5	0	0.158	1	0.013
14	009037C	000740ND	000741ND	81.908	Circular	1.5	0	2	0	10.316	1	0.013
14	009037D	000741ND	005658IN	321.81	Circular	1.5	0	2.5	0	3.542	1	0.013
15	007869STMP	007226IN	007227IN	108.519	Circular	1.25	0	2.5	0	1.422	1	0.013
15	007870STMP	007227IN	003062SMH	33.197	Circular	1.25	0	2	0	4.234	1	0.013
15	009364STMP	003476SMH	008027IN	268.47	Circular	1.5	0	2.5	0	0.676	2	0.013
15	009875STMP	003478SMH	003476SMH	32.475	Circular	1.5	0	3	0	-2.447	1	0.013
15	010111STMP	003062SMH	003195SMH	31.469	Circular	1.5	0	2.5	0	-2.226	1	0.013
15	010112STMP	003195SMH	000874ND	74.152	Circular	1.5	0	3	0	-0.344	2	0.013

Appendix B - Conveyance Solutions

Summary of 23 Conveyance Solutions developed for Hooffs Run High Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Shape	Existing Diameter/ Height (ft)	Existing Bottom Width (ft)	Proposed Diameter/ Height (ft)	Proposed Bottom Width (ft)	Conduit Slope	Number of Barrels	Roughness
15	010415STMP	003486SMH	003478SMH	87.123	Circular	1.25	0	3	0	1.369	1	0.013
15	010436STMP	008046IN	003486SMH	54.379	Circular	1.25	0	2.5	0	5.41	1	0.013
15	014940STMP	000874ND	008046IN	151.744	Circular	1.25	0	3	0	-0.344	2	0.013
16	009131STMP	002622SMH	002623SMH	139.363	Circular	2	0	3	0	6.006	1	0.013
16	009132STMP	002623SMH	002624SMH	79.701	Circular	2	0	3	0	6.035	1	0.013
16	009134STMP	002624SMH	002625SMH	172.743	Circular	2	0	2.5	0	7.865	1	0.013
16	009135STMP	002625SMH	007940IN	592.932	Circular	2	0	3	0	3.224	1	0.013
16	010318A	003492SMH	0001040ND	33.073	Circular	2.25	0	3	0	2.196	2	0.013
16	010318B	0001040ND	004000SMH	45.695	Circular	2.25	0	3	0	1.584	2	0.013
16	010319STMP	007939IN	003492SMH	22.319	Circular	2.25	0	3	0	2.15	2	0.013
16	010323STMP	003493SMH	007939IN	118.607	Circular	2.25	0	3	0	2.15	2	0.013
16	010324STMP	003494SMH	003493SMH	174.053	Circular	2.25	0	3	0	2.361	2	0.013
16	010326STMP	007940IN	003494SMH	10.104	Circular	2	0	2.5	0	3.959	2	0.013
16	014000STMP	004000SMH	002907ND	81.511	Circular	2.25	0	3	0	8.807	1	0.013
17	010025STMP	003202SMH	003204SMH	11.896	Circular	1.5	0	2	0	3.525	1	0.013
17	010028STMP	003204SMH	003205SMH	690.648	Circular	2	0	2.5	0	1.366	1	0.013
17	010031STMP	003205SMH	006036IN	247.146	Circular	2.25	0	3	0	1.409	1	0.013
17	010032STMP	006036IN	002911ND	4.073	Circular	2.25	0	3.5	0	1.409	1	0.013
18	008366STMP	003123SMH	003143SMH	21.776	Circular	1.25	0	2	0	1.072	1	0.013
18	008558STMP	007718IN	003134SMH	82.802	Circular	2	0	3	0	1.994	1	0.013
18	008560STMP	003137SMH	007718IN	29.825	Circular	2	0	3	0	-2.334	1	0.013
18	008563STMP	007721IN	003137SMH	15.586	Circular	1.5	0	2	0	3.596	1	0.013
18	008566STMP	003138SMH	007721IN	26.538	Circular	1.5	0	2.5	0	1.069	1	0.013
18	008630STMP	003145SMH	003123SMH	97.892	Circular	1.25	0	2	0	1.222	1	0.013
18	008635STMP	003143SMH	003138SMH	276.995	Circular	1.5	0	2	0	1.559	1	0.013
19	008648C	000902ND	003217SMH	81.213	Rectangular	5	5	4	8	0.243	1	0.013
19	008706A	003407SMH	000950ND	11.086	Rectangular	5	5	4	8	-0.024	1	0.013
19	008706B	000950ND	000949ND	24.637	Rectangular	5	5	4	8	-0.024	1	0.013
19	008753A	003408SMH	000953ND	22.644	Rectangular	5	5	4	8	0.145	1	0.013
19	008753B	000953ND	000952ND	109.191	Rectangular	5	5	4	8	0.145	1	0.013
19	008753C	000952ND	000951ND	105.313	Rectangular	5	5	4	8	0.145	1	0.013
19	008753D	000951ND	003407SMH	11.159	Rectangular	5	5	4	8	0.145	1	0.013
19	008754STMP	003217SMH	003408SMH	362.314	Rectangular	5	5	4	8	0.182	1	0.013
20	009848STMP	006052IN	003283SMH	25.441	Circular	1	0	1.5	0	5.066	1	0.013
20	010146STMP	003284SMH	006053IN	8.581	Circular	1	0	1.5	0	50.78	1	0.013
20	010148STMP	003286SMH	003287SMH	123.271	Circular	0.833	0	1.5	0	12.789	1	0.013
20	010149B	000922ND	003286SMH	108.508	Circular	0.667	0	2	0	4.723	1	0.013
20	010150STMP	003287SMH	003284SMH	237.927	Circular	1	0	2	0	10.815	1	0.013
20	010456STMP	003495SMH	006052IN	90.785	Circular	1	0	1.5	0	12.282	1	0.013
20	010457STMP	008054IN	003495SMH	94.359	Circular	1	0	1.5	0	7.427	1	0.013
21	009726STMP	006023IN	006025IN	182.475	Circular	1.5	0	2.5	0	2.094	1	0.013
21	010178STMP	003302SMH	006111IN	175.173	Circular	2	0	3	0	1.005	1	0.013

Appendix B - Conveyance Solutions

Summary of 23 Conveyance Solutions developed for Hooffs Run High Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Shape	Existing Diameter/ Height (ft)	Existing Bottom Width (ft)	Proposed Diameter/ Height (ft)	Proposed Bottom Width (ft)	Conduit Slope	Number of Barrels	Roughness
21	010179STMP	006112IN	003302SMH	30.38	Circular	2	0	2.5	0	1.975	1	0.013
21	010180STMP	006113IN	006112IN	13.087	Circular	1.75	0	2.5	0	4.39	1	0.013
21	010181STMP	006025IN	006113IN	217.268	Circular	1.75	0	3	0	0.58	1	0.013
22	009550STMP	003334SMH	000991ND	5.869	Circular	1.25	0	1.5	0	24.995	1	0.013
22	010299STMP	006240IN	003334SMH	166.344	Circular	1.25	0	2.5	0	0.05	2	0.013
22	010335STMP	000608CB	006240IN	163.512	Circular	1.25	0	2	0	2.375	1	0.013
23	010222STMP	006136IN	006137IN	244.012	Circular	2.5	0	3	0	1.164	1	0.013
23	010223STMP	006137IN	003318SMH	39.976	Circular	2.5	0	3.5	0	0.976	1	0.013
23	010227STMP	003318SMH	003320SMH	109.036	Circular	1.5	0	4	0	0.367	1	0.013

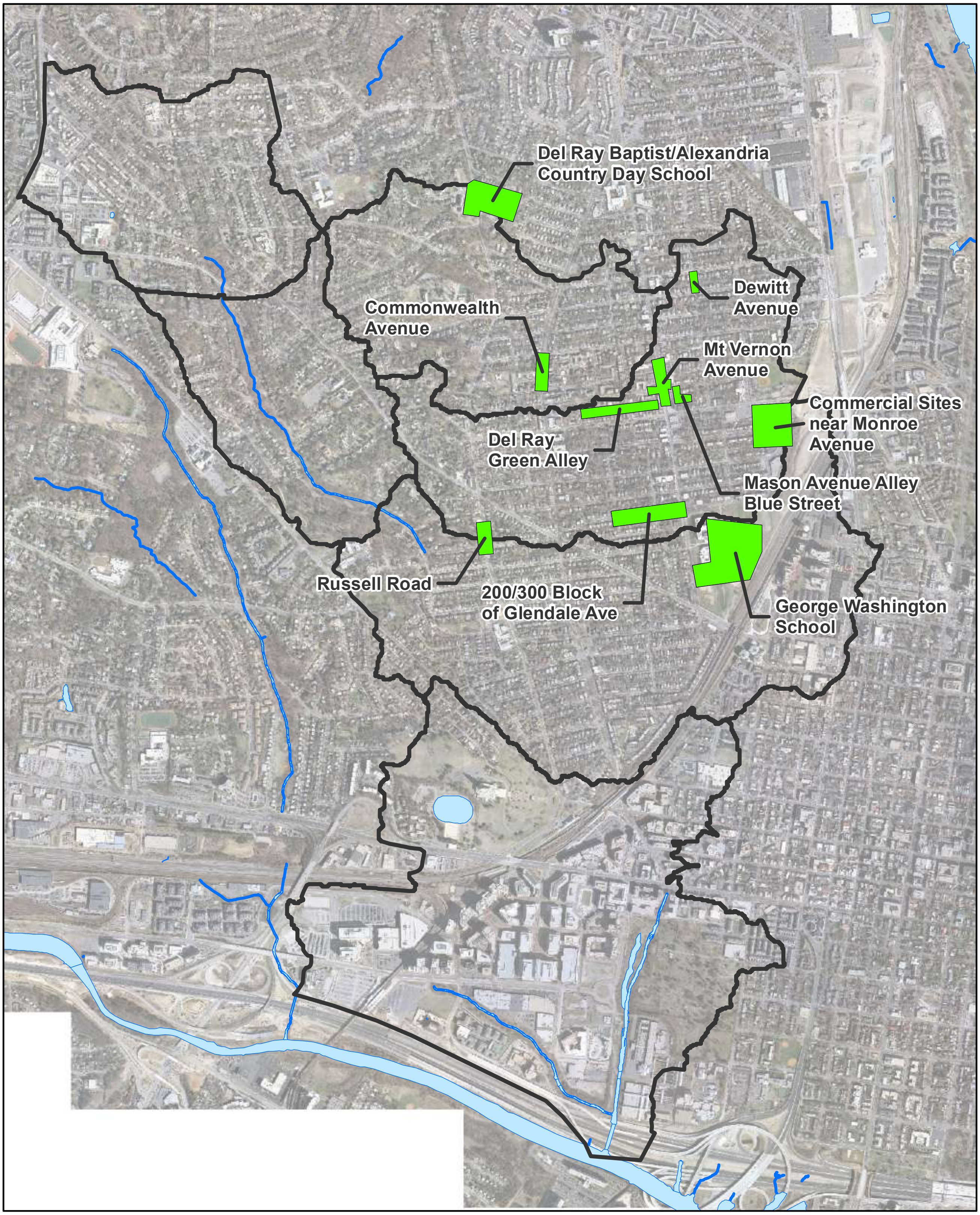
Appendix C
Storage Solutions

Appendix C - Storage Solutions

Summary of Storage Solutions developed for Hooffs Run High Priority Problem Areas

Problem Area	Storage ID	Overflow Node	Discharge Node	Storage Area (ac)	Storage Area (ft^2)	Overflow Weir Crest	Overflow Weir Crown	Storage Invert Elevation (ft)	Storage Rim Elevation (ft)	Storage Depth (ft)	Storage Volume (ft^3)	Notes
1	1	000843ND	000849ND	0.17	7,537	34.70	37.90	31.73	36	4.27	32,177	
2	2	000837ND.1	003352SMH	0.71	30,812	33.87	35.61	30.17	40	9.83	302,881	
2	6	003215SMH	000888ND	0.08	3,528	29.27	30.37	26.29	32	5.71	20,147	
2	7	003388SMH	003402SMH	0.31	13,492	26.63	30.07	24.61	32	7.39	99,707	
3	3	003465SMH	003456SMH	1.19	51,875	28.24	30.89	20.00	30	10.0	518,745	
3	17	008027IN	003472SMH	1.04	45,140	36.83	38.04	30.00	40	10.0	451,404	
4	4	006548IN	001131ND	0.07	3,035	31.26	33.81	27.66	34	6.34	19,228	
4	5	002022SMH	001974SMH	0.11	4,984	36.44	41.44	32.65	42	9.35	46,605	Up to 15 ft wide by 330 ft long storage pipe; depth not to exceed 9.3 ft
5	12	003273SMH	003264SMH	0.74	32,172	18.60	23.32	14.00	24	10.0	321,719	
6	9	001992SMH	003339SMH	0.17	7,599	33.88	38.16	30.78	40	9.22	70,064	
6	10	003051SMH	003337SMH	0.25	10,792	34.46	38.87	28.83	38	9.17	98,966	
7	13	000735ND.1	000734ND	0.40	17,471	148.13	149.90	144.99	150	5.01	87,531	
8	14	003412SMH	000936ND	0.25	10,913	29.47	30.58	25.38	34	8.62	94,029	
8	15	003421SMH	003418SMH	0.27	11,819	30.60	31.97	26.00	30	4.00	47,277	
10	16	003167SMH	005909IN	1.06	46,347	36.67	42.27	26.00	36	10.0	463,473	
11	21	003212MH.1	001010ND	0.10	4,396	49.65	53.40	44.80	54	9.20	40,432	
12	18	001636SMH	001611SMH	0.41	17,872	30.31	33.88	28.00	38	10.0	178,721	
15	8	007227IN	008046IN	0.33	14,161	42.51	45.78	40.63	46	5.37	76,017	
16	25	002623SMH	003494SMH	0.13	5,766	111.07	114.57	103.00	110	7.00	40,363	Storage in 7 x 7 box culvert adjacent to or under stream bed; modeled as storage node; rim and storage invert are estimates for the sake of modeling
17	19	003205SMH	002911ND	0.54	23,542	12.64	13.89	7.06	14	6.94	163,310	
18	20	007718IN	005981IN	4.24	184,481	29.89	32.04	24.00	34	10.0	1,844,814	
19	11	000990ND	001001ND	0.42	18,410	32.49	33.90	27.17	36	8.83	162,512	
21	23	006025IN	006111IN	0.87	37,883	12.71	15.85	8.00	18	10.0	378,828	
22	22	000608CB	006240IN	0.08	3,554	34.75	37.90	29.62	34	4.38	15,572	
23	24	006137IN	003320SMH	0.13	5,822	12.51	14.53	9.06	16	6.94	40,405	

Appendix D
Green Infrastructure Concept Plans



LEGEND

Concept Locations

Subwatersheds

Water Bodies

City of Alexandria
Streams

0 625 1,250 2,500
Feet

N

Task 4 Green Infrastructure Program
Concept Plan Locations for Hooffs Run
Task 4 Problem and Solution Identification and Prioritization for Hooffs Run

CH2MHILL

Potential Sites for Task 4 Concept Development in Hooffs Run

PREPARED FOR: City of Alexandria TE&S Department

COPY TO: File

PREPARED BY: CH2M HILL

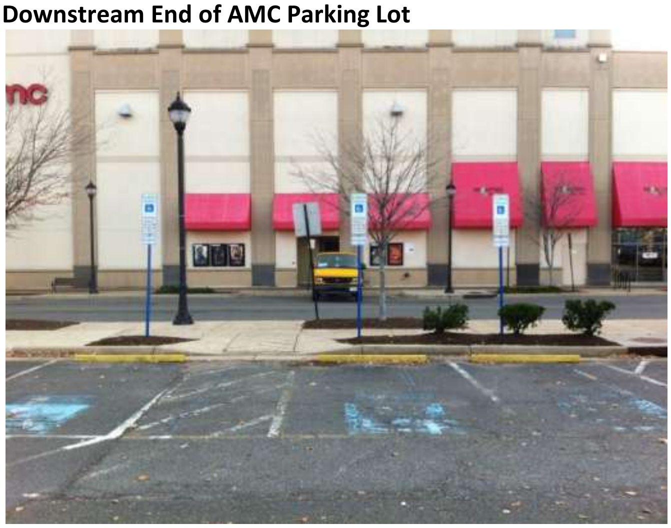
DATE: January 3, 2013

PROJECT NUMBER: 240027

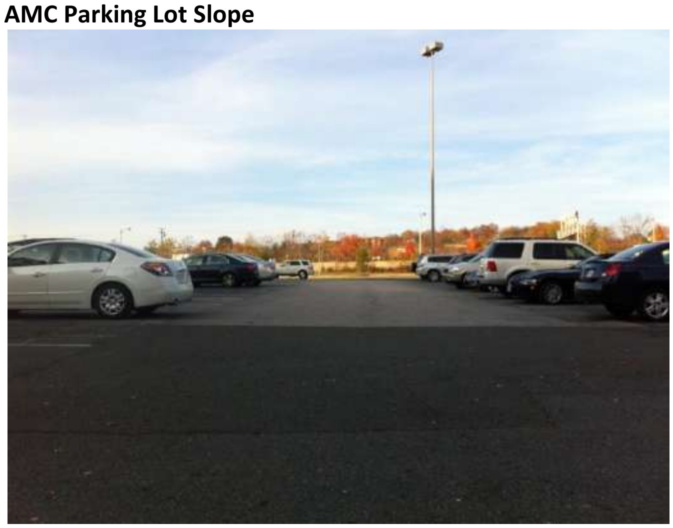
The following is documentation of the sites identified as potential locations for green infrastructure (GI) concept development in Hooffs Run. For each site a program and the elements of the program are identified with field notes as well as pros and cons of GI implementation. Sites are described with the southernmost site in Hooffs Run first, moving north into the watershed. A map of the water shed and all potential sites, as well as a detailed map of each individual site, is provided in Appendix A for reference.

AMC Theater and Parking Lot

Downstream End of AMC Parking Lot



AMC Parking Lot Slope



Program Type: Green Buildings, Green Parking

GI Concepts: Planters/Bioretention, Porous Pavement

Field Notes:

- Planters can be placed along sidewalk adjacent to buildings to capture runoff from roof drains (theater and adjacent buildings)
- Large parking lot is usually relatively empty
- Site is close to Old Cameron Run stream, so infiltration should not be a problem in terms of impacting existing structure
- Parking lot slopes dramatically to south and is in poor condition
- Bioretention can be placed in grassy area on north side of parking lot to capture runoff from roadway

Pros:

- Large stormwater capture potential
- Slope of lot makes capture easy at downstream end of parking lot
- Parking areas are typically easier and more cost effective to implement
- Good infiltration potential

Cons:

- Large slope decreases area available to implement GI practices
- Downstream capacity limitations are not severe
- Near the bottom of the watershed
- Requires coordination with private property owners

Alexandria Amtrak Station

King Street Upstream of Amtrak Station

Green Space with Depression in front of Station

Program Type: Detention, Green Parking, Green Buildings,

GI Concepts: Detention (surface capture of road runoff, and/or underground detention storage to offload existing pipes), Porous Pavement (parking lot), potential for rainwater harvesting and reuse in train station toilets

Field Notes:

- City has known flooding at bottom of hill near station (King Street between Russell Road and Sunset Drive)
- George Giuseppe believes flooding is due to decreased inlet capacity caused by road paving activities
- There are plans to update this area of King Street providing opportunity for drainage system modifications
- Amtrak Station building shown as owned by City of Alexandria, which may allow for water reuse elements
- Project could be combined with stormwater management efforts at Masonic Temple

Pros:

- City owned property
- Public visibility of improvements
- Water reuse opportunities
- Potential to piggy back on another improvement project

- Green space with depression available for detention
- Targets a known problem area

Cons:

- If flooding is mostly due to inlet capacity issues, need to identify how to capture flow from roadway
- Property ownership coordination could be a challenge with Masonic Temple

Masonic Memorial

Masonic Memorial Parking Lot

Program Type: Green Parking, Open Space

GI Concepts: Porous pavement (parking area), Bioretention/Planters and/or Amended Soils and redirect runoff from storm drains onto green space

Field Notes:

- Large impervious areas directly connected into the storm pipes, including large flat parking lot in poor condition behind Masonic Memorial
- Parking lot receives limited runoff, but flow from a portion of the memorial could be redirected to lot and stored
- Runoff from front side of memorial is directed straight into the storm drains rather than onto lawn

Pros:

- Large open space
- Large potential stormwater capture
- Parking areas typically are simpler construction and more cost-effective to implement

- Up gradient of known flooding area
- Work on front side of memorial would have high visibility by City residents

Cons:

- Private property
- Parking area has poor visibility by City residents (assuming this is mainly used by visitors)
- There is limited potential for amending soils in other areas of city due to lack of open space, therefore there is limited potential for scaling this portion of the concept

Hillside Lane Alleys/Highland Place Alleys

Hillside Lane from Park Road

Ridge Lane

Highland Ave at Outlook Lane

Highland Ave Alley between Hilltop Terrace and Braxton Pl

Program Type: Green Streets/Alleys (Alley)

GI Concepts: Porous Pavement

Field Notes:

- Alleys slope uniformly down to Hillside Lane/Highland Place

- Pavement appears to be in poor condition
- Hillside Lane alleys are in headwaters of flooding on King Street between Russell Rd and Sunset Dr
- Highland Place alleys in headwaters of significant flooding near Russell Rd between W. Masonic View Avenue and W. Walnut Street

Pros:

- Alley could use rehabilitation and green infrastructure would likely be well-received by community
- Could provide relief to pipes with deficient capacity downstream
- Location on hill minimizes concern over infiltration

Cons:

- Narrow construction access
- Stormwater benefit would be largely from residential properties
- Capture efficiency would have to be further evaluated, partially out of Hooffs Run

Maury School & Beach Park

Maury School Parking

Beach Park

Program Type: Green Schools, Open Space

GI Concepts: Porous Pavement, Detention, Stream Daylighting

Field Notes:

- School has large flat parking lot and playground with grate inlets draining runoff from roof and parking/blacktop surfaces
- Park provides ample green space for stormwater management
- Site is upstream of significant capacity limitations

Pros:

- Large stormwater capture and storage potential
- Educational opportunities at the school
- Open space and parking areas typically easier and more cost-effective to implement
- Potential to improve playground/blacktop surface

- Opportunity to improve park and add dual use pond or natural water feature for community

Cons:

- Potential perceived loss of active park space with addition of stream
- Potential community concern over safety with open water adjacent to an elementary school
- Construction possibly limited to summer months (on the school parcel)

Russell Rd. and Glendale Ave. Traffic Calming

Russell Road at Glendale Ave

Program Type: Green Streets - Arterial

GI Concepts: Bioretention/Planters (Traffic-calming stormwater planters in lieu of paver humps)

Field Notes: Wide right-of-way with paver traffic humps

Pros:

- Large stormwater capture potential
- High visibility
- Creation of new green space

Cons:

- Traffic calming has mixed community acceptance
- May require traffic study

George Washington Middle School, 1005 Mt. Vernon Ave

Median Bioretention at Access Drive

Porous Pavement Parking Areas

Program Type: Green Schools

GI Concepts: Porous Pavement Parking, Median Bioretention, Green/Blue Roof

Field Notes:

- Large asphalt parking lot and access drives are all in relatively poor condition
- The parking area surface drainage splits flow towards a large collection system near the bus lane, and a low point to the southeast (near the baseball field)
- The main access drive drains to a median gutter
- All grass/tree medians and traffic islands have raised curbs
- The school has large sections of flat roofing

Pros:

- Large stormwater capture potential
- Median stormwater capture and soil amendment will promote larger tree growth
- School roof likely has areas that would support green/blue roof
- Educational value
- Parking areas typically easier and more cost-effective to implement
- Opportunity for integration with capital improvements at school (e.g. roof replacement, parking lot repaving)

Cons:

- Possibly limited to summer construction
- Full pavement rehabilitation may be desired with GI implementation, increasing costs or requiring cost-sharing

E. Glendale Ave. (200/300 Blocks) 90° Parking

E Glendale Ave at Wayne Street (Looking East)

E Glendale Ave at Mt. Vernon (Looking West)

Program Type: Green Streets/Alleys (Residential)

GI Concepts: Porous Pavement (parking)

Field Notes: Very wide, crowned roadway drains to 90° on-street parking

Pros:

- Parking areas typically are simpler construction and more cost-effective to implement
- Flat, large potential stormwater capture
- Generally good separation from buildings

Cons: Dedicated residential parking will be lost during construction

Commercial Sites and Commonwealth Academy near E. Monroe Ave.

Leslie Ave & E Nelson Ave

E Monroe Ave & Leslie Ave

Program Type: Green/Blue Roofs, Green Buildings

GI Concepts: Green/Blue Roofs, Bioretention/Planers, and Cisterns

Field Notes:

- Large commercial/educational buildings upstream of significant capacity limitations along E. Monroe Ave.
- Limited parking and ROW along Leslie Ave.

- E. Monroe was recently repaved near the intersection of Leslie Ave.

Pros:

- Large commercial buildings with flat roofs
- Potential for removing significant amount of impervious area upstream of significant capacity limitation
- Energy savings potential for businesses

Cons:

- Privately owned buildings
- Limited ROW for GI at grade
- Intersection of E Monroe Ave & Leslie Ave appears to have been recently updated, so planning a new project may not be widely accepted by businesses and residents
- School site may be limited to summer construction

Mason Ave Green Alley

Alley South of E Mason Ave

Alley South of E Mason Ave

Program Type: Blue Streets (Alley)

GI Concepts: Surface Storage

Field Notes:

- Alley sewer appears to receive inflow from adjacent residential parcels and commercial business
- Full of debris and vegetation
- Appears rarely utilized for vehicle traffic

Pros:

- Large stormwater capture potential
- Alley could use revitalization or repurposing as a pedestrian-only alley

Cons:

- Would require coordination with adjacent retaining wall structures
- Narrow construction access
- Very low visibility

Mt. Vernon Ave. (1600/1700 Blocks)

Looking North at Intersection of Mt. Vernon and E. Mason

Intersection of Mt. Vernon and E. Mason (Looking West)

Program Type: Green Streets/Alleys (Commercial)

GI Concepts: Porous Pavement (pavers), Bioretention/Planters (sidewalk)

Field Notes:

- Wide right-of-way with pavement, curb, and sidewalk all in good condition
- Higher/heavier traffic area with numerous subsurface utilities

Pros:

- Large stormwater capture potential
- High visibility
- Creation of new green space
- Enhancement of commercial district
- Traffic calming

Cons:

- More complex and costly to construct
- Requires significant public outreach

Del Ray Green Alley – Mt. Vernon Ave. to Newton St.

Alley from Newton St between Mason Ave & Monroe Ave

Program Type: Green Streets/Alleys (Alley)

GI Concepts: Porous Pavement

Field Notes:

- Alley slopes uniformly down to Newton Ave
- Pavement is in poor condition

Pros:

- Alley could use rehabilitation
- Green infrastructure would likely be well-received by community

Cons:

- Narrow construction access
- Stormwater benefit would be largely from residential properties
- Capture efficiency would have to be evaluated

Commonwealth Ave (1700/1800 Block)

Commonwealth Ave & Bellefonte Ave (Looking South)

Commonwealth Ave & Cliff St (Looking North)

Program Type: Green Streets/Alleys (Arterial) **GI Concepts:** Bioretention, Tree plantings

Field Notes:

- Wide right-of-way with wide median in Commonwealth Ave between Cliff St. and Bellefonte Ave.
- Generally poor ground vegetation in median

Pros:

- Vegetated median available
- Opportunity for beatification and rehabilitation of green space
- High visibility

Cons:

- Existing pavement is in good condition
- Appears that only left travel lane slopes to median
- Work around large trees and high traffic area

Dewitt Ave. between Custis and Windsor Ave.

Looking North at Intersection of Dewitt and Custis

Looking South at Intersection of Dewitt and Windsor

Program Type: Blue Street or Green Streets/Alleys (Residential)

GI Concepts: Subsurface detention/slow release; possibly combine with inlet flow regulators for temporary surface storage (i.e., residential “Blue Streets”). Where ROW width/use and overhead utilities allow, residential “Green Streets” could implement bioretention and/or tree plantings/trenches.

Field Notes:

- Small right-of-way, but still wider than many residential streets in the sewershed
- Pavement and curbing is in fair condition

Pros (Blue Street):

- Relatively easy and cost-effective to construct using standard materials
- Less maintenance, typical residential street (scalable)
- Opportunity for comparison of green and blue streets

Cons (Blue Street):

- Less visibility
- Public perception of temporary street surface storage

Pros (Green Street):

- More green space and tree canopy
- Better water quality treatment relative to blue streets

Cons (Green Street):

- Typically restricts vehicular traffic or parking
- Requiring more public interaction and outreach

Del Ray Baptist Church/Alexandria Country Day School

North/Central Section of Church Lot

Day School Green Space between Lot and Russell Rd.

Program Type: Green Parking, Green Buildings

GI Concepts: Porous Pavement, Bioretention/Planters

Field Notes:

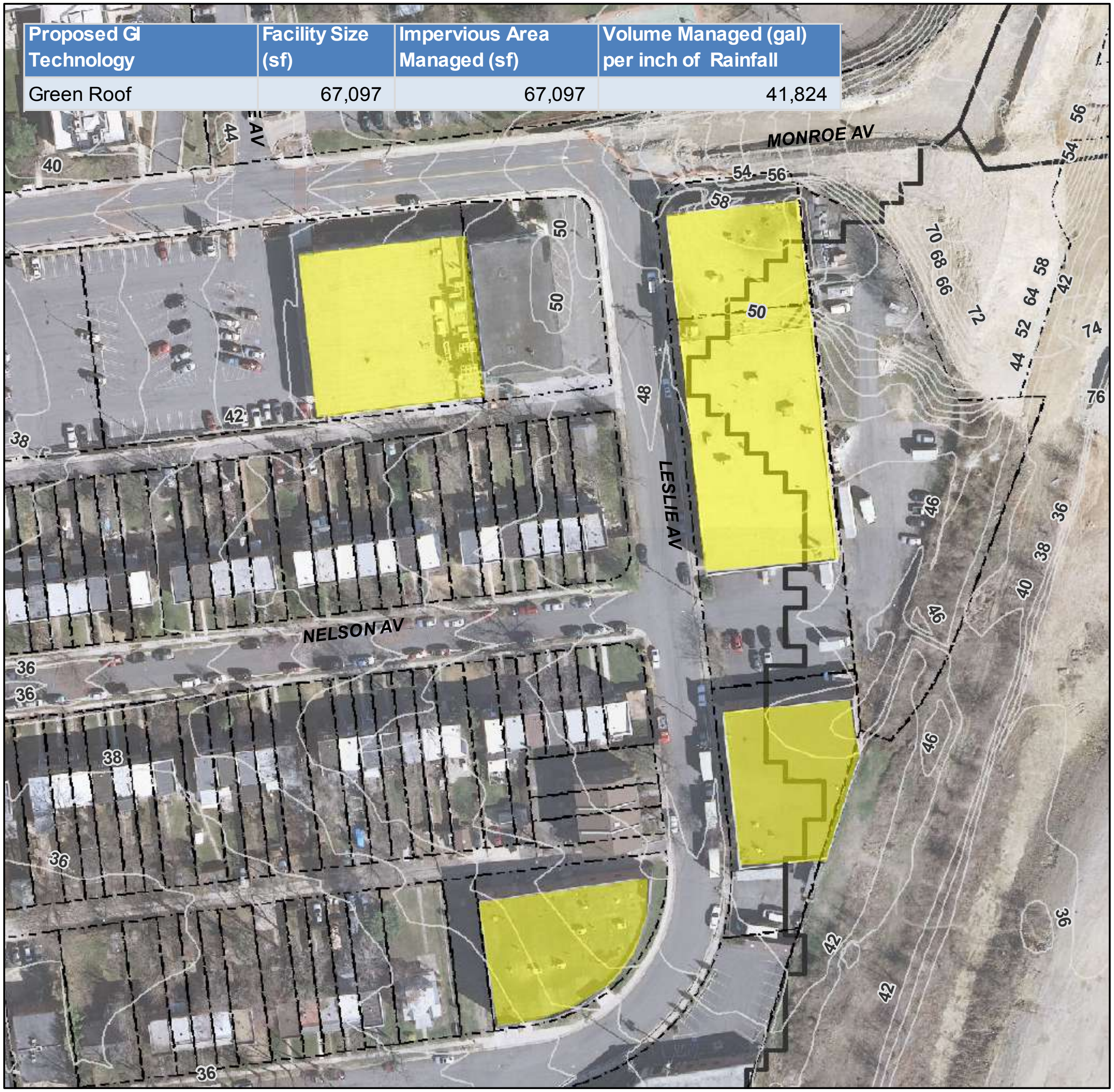
- Church has deteriorated pavement and curbed medians
- Day school lot recently constructed but has large green space frontage adjacent to Russell Road
- Most roof leaders for both buildings are external and could be re-routed

Pros:

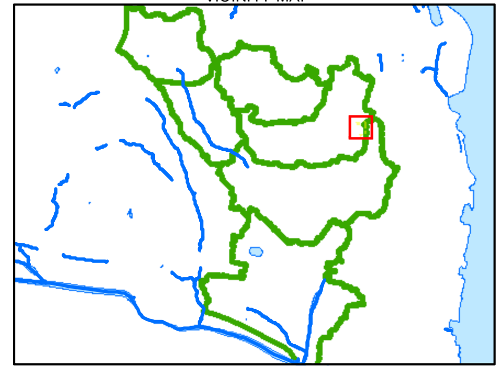
- Large stormwater capture potential
- High incremental benefit for non-public landowners
- Could link with private infrastructure reconstruction/maintenance
- Near the top of the watershed

Cons: Private property partnership required

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal) per inch of Rainfall
Green Roof	67,097	67,097	41,824



VICINITY MAP



LEGEND

- Contours (ft)
- Parcel Boundary
- City of Alexandria Streams
- Water Bodies
- Watershed

Green Infrastructure Concepts

- Bioretention/Planters
- Cisterns
- Green/Blue Roofs
- Porous Pavement
- Stream Daylighting
- Surface Storage (Blue Streets)

N

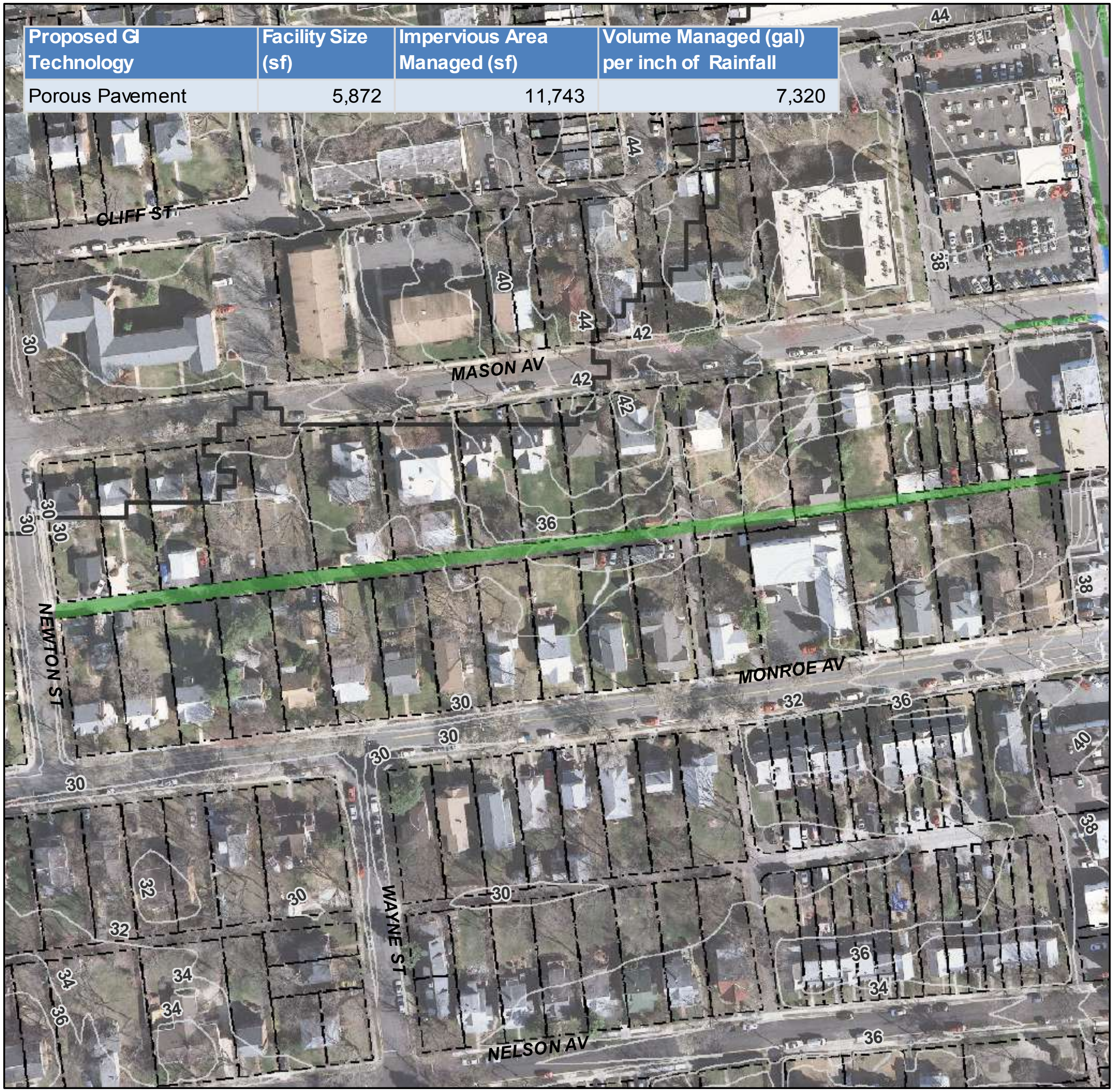
0 50 100 200
Feet

Commercial Sites near Monroe Ave

Green Roofs, Bioretention/Planters, Cisterns
Task 4 - Identify Problems and Develop Solutions
City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal) per inch of Rainfall
Porous Pavement	5,872	11,743	7,320



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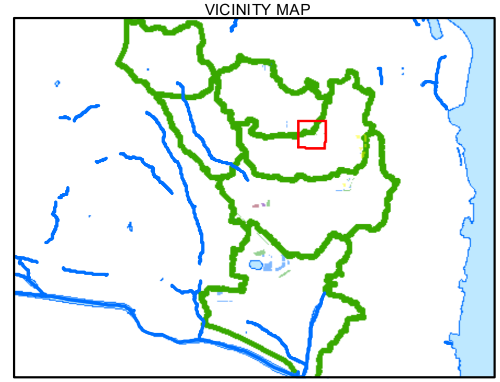


LEGEND

- Contours (ft)
- Parcel Boundary
- City of Alexandria Streams
- Water Bodies
- Watershed

Green Infrastructure Concepts

- Bioretention/Planters
- Cisterns
- Green/Blue Roofs
- Porous Pavement
- Stream Daylighting
- Surface Storage (Blue Streets)

N

0 50 100 200
Feet

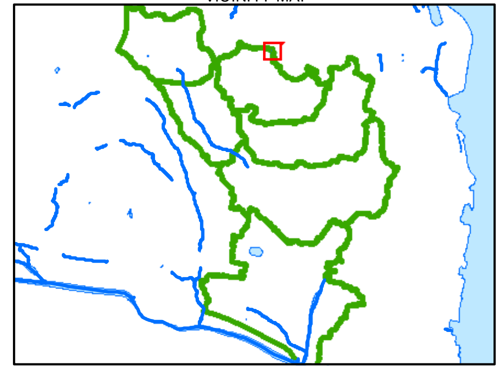
Del Ray Green Alley

Green Streets/Alleys - Porous Pavement
Task 4 - Identify Problems and Develop Solutions
City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal) per inch of Rainfall
Bioretention/Planters	7,996	95,948	59,808
Porous Pavement	19,045	38,090	23,743
Total	**27,041**	**134,039**	**83,551**

VICINITY MAP



LEGEND

- Contours (ft)
- Parcel Boundary
- City of Alexandria Streams
- Water Bodies
- Watershed

Green Infrastructure Concepts

- Bioretention/Planters
- Cisterns
- Green/Blue Roofs
- Porous Pavement
- Stream Daylighting
- Surface Storage (Blue Streets)

N

0 50 100 200

Feet

Del Ray Baptist/Alexandria Country Day School

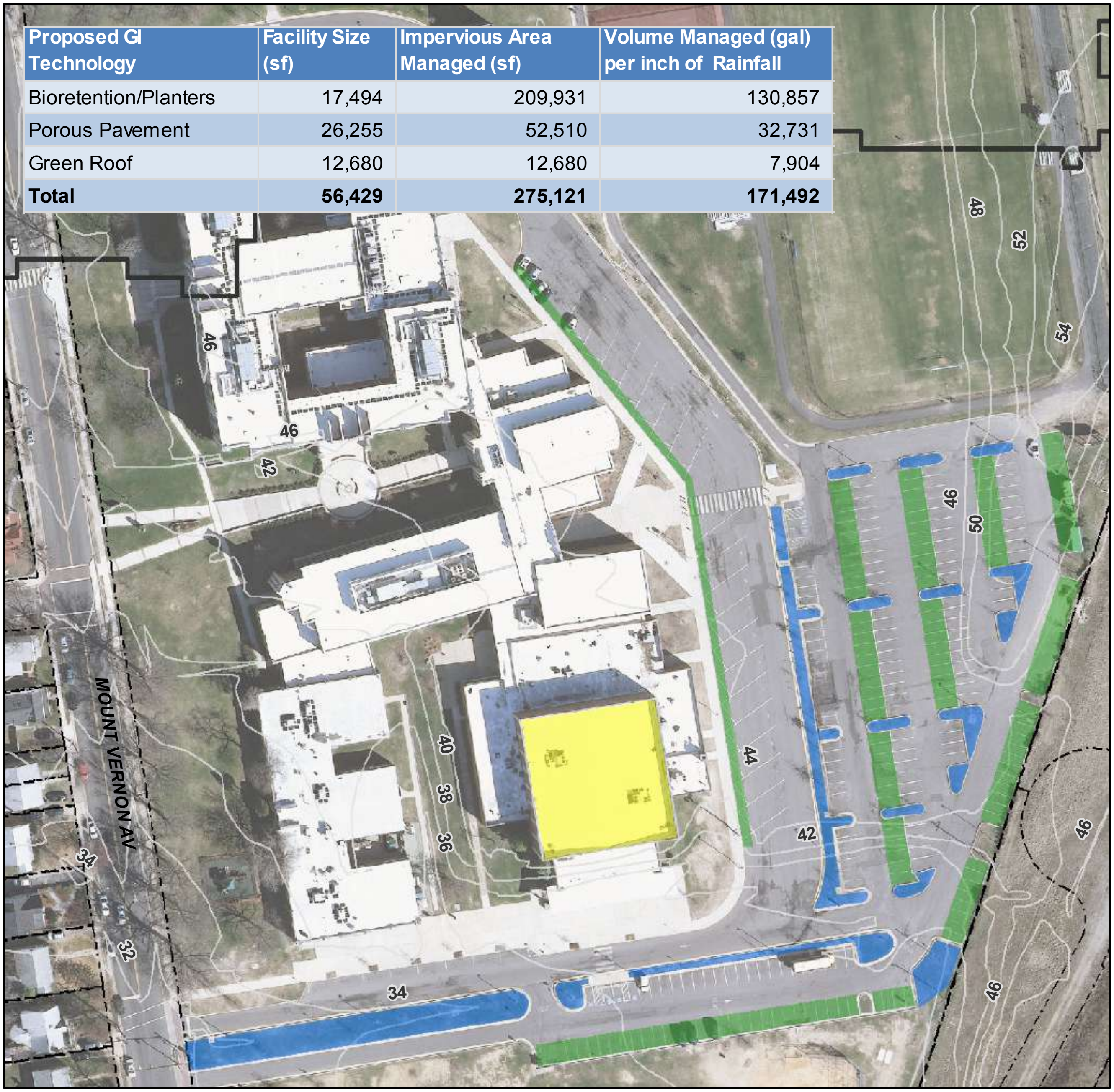
Green Parking - Bioretention/Planters, Porous Pavement

Task 4 - Identify Problems and Develop Solutions

City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal) per inch of Rainfall
Bioretention/Planters	17,494	209,931	130,857
Porous Pavement	26,255	52,510	32,731
Green Roof	12,680	12,680	7,904
Total	**56,429**	**275,121**	**171,492**



VICINITY MAP

LEGEND

- Contours (ft)
- Parcel Boundary
- City of Alexandria Streams
- Water Bodies
- Watershed

Green Infrastructure Concepts

- Bioretention/Planters
- Cisterns
- Green/Blue Roofs
- Porous Pavement
- Stream Daylighting
- Surface Storage (Blue Streets)

N

0 50 100 200

Feet

George Washington School

Green Schools - Bioretention/Planters, Green Roofs, Porous Pavement

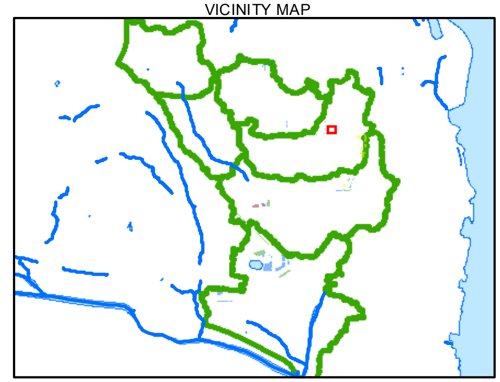
Task 4 - Identify Problems and Develop Solutions

City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal) per inch of Rainfall
Surface Storage	2,852	2,852	1,778

VICINITY MAP



LEGEND

- Contours (ft)
- Parcel Boundary
- City of Alexandria Streams
- Water Bodies
- Watershed

Green Infrastructure Concepts

- Bioretention/Planters
- Cisterns
- Green/Blue Roofs
- Porous Pavement
- Stream Daylighting
- Surface Storage (Blue Streets)

N

0 15 30 60
Feet

Mason Avenue Alley Blue Street

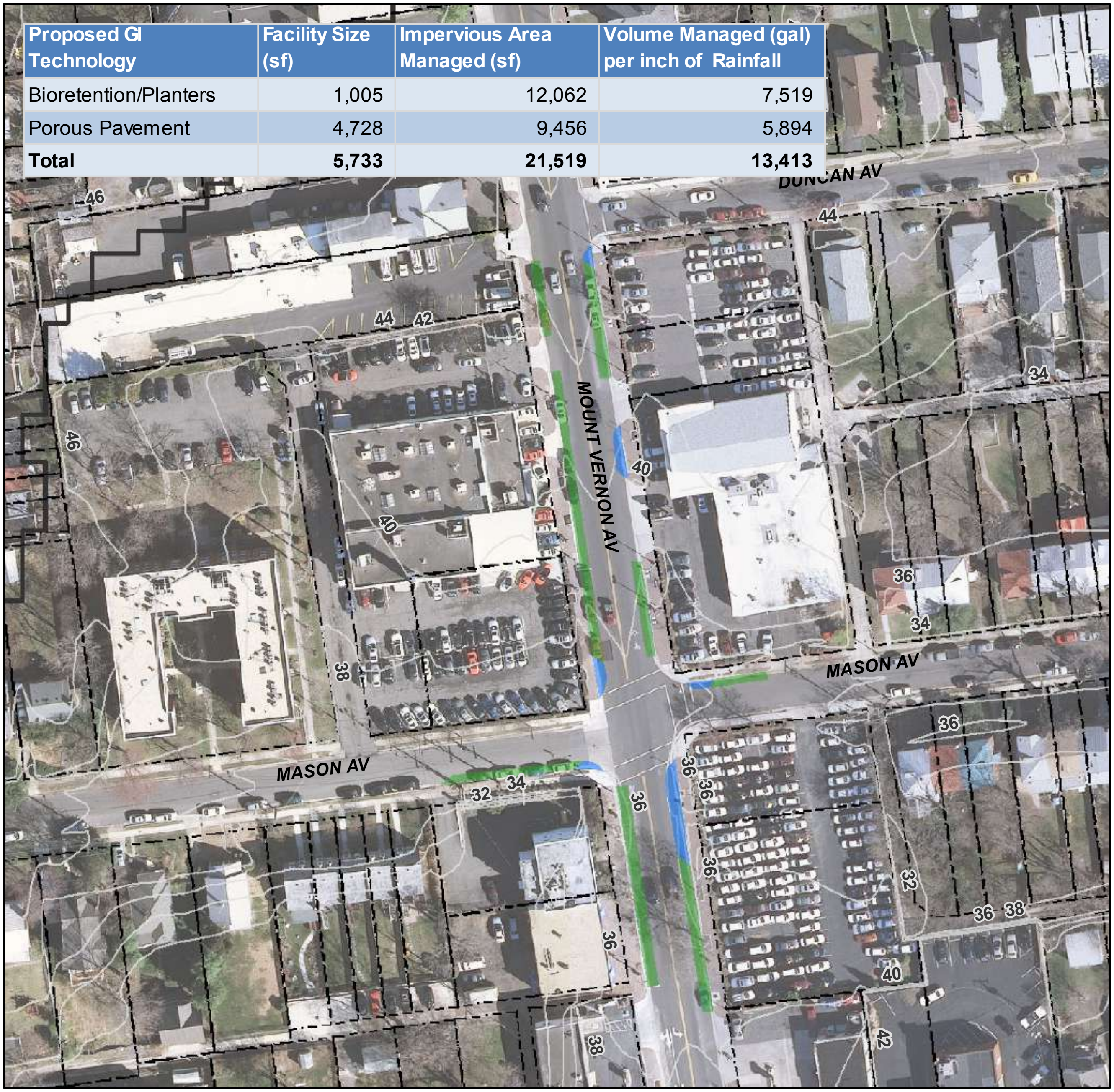
Blue Streets/Alleys - Surface Storage

Task 4 - Identify Problems and Develop Solutions

City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal) per inch of Rainfall
Bioretention/Planters	1,005	12,062	7,519
Porous Pavement	4,728	9,456	5,894
Total	**5,733**	**21,519**	**13,413**



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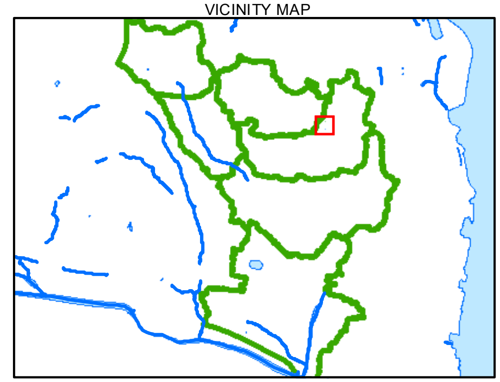


LEGEND

- Contours (ft)
- Parcel Boundary
- City of Alexandria Streams
- Water Bodies
- Watershed

Green Infrastructure Concepts

- Bioretention/Planters
- Cisterns
- Green/Blue Roofs
- Porous Pavement
- Stream Daylighting
- Surface Storage (Blue Streets)

N

0 50 100 200

Feet

Mt. Vernon Avenue

Green Streets/Alleys - Bioretention/Planters, Porous Pavement

Task 4 - Identify Problems and Develop Solutions

City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL

FACT SHEET: BIORETENTION AND STORMWATER PLANTERS

Rain garden in a public park setting in Lancaster, PA

Right-of-way bioretention planting in Syracuse, NY

Bioretention areas (often called Rain Gardens) are shallow surface depressions planted with specially selected native vegetation to treat and capture runoff and are sometimes underlain by sand or a gravel storage/infiltration bed. Bioretention is a method of managing stormwater by pooling water within a planting area and then allowing the water to infiltrate into the garden soils. In addition to managing runoff volume and mitigating peak discharge rates, this process filters suspended solids and related pollutants from stormwater runoff.

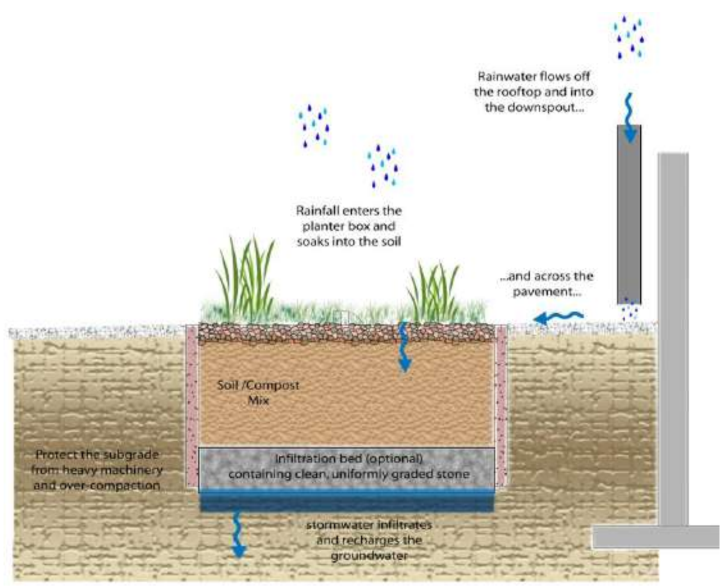
Bioretention can be designed into a landscape as a garden feature that helps to improve water quality while reducing runoff quantity. Rain Gardens can be integrated into a site with a high degree of flexibility and can balance nicely with other structural management systems including porous pavement parking lots, infiltration trenches, and non-structural stormwater BMPs. Bioretention areas typically require little maintenance once fully established and often replace areas that were intensively landscaped and required high maintenance.

A Stormwater Planter is a container or enclosed feature located either above ground or below ground, planted with vegetation that captures stormwater within the structure itself.

BENEFITS

- Volume control & GW recharge, moderate peak rate control
- Versatile w/ broad applicability
- Enhanced site aesthetics and habitat
- Potential air quality & climate benefits

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra-Urban	Yes (Planters)
Industrial	Yes
Retrofit	Yes
Recreational	Yes
Public/Private	Yes



Conceptual cross-section showing planter with infiltration

VARIATIONS

- Subsurface storage/infiltration bed
- Use of underdrain and/or impervious liner
- Planters – Contained (above ground), infiltration (below ground), flow-through
- Pre-treatment incorporated into design

KEY DESIGN FEATURES

- Ponding depths 6 to 18 inches for drawdown within 48 hours
- Plant selection (native vegetation that is tolerant of hydrologic variability, salts, and environmental stress)
- Amended or engineered soil as needed
- Stable inflow/outflow conditions and positive overflow for extreme storm events
- Planters may require flow bypass during winter
- Planters - Captured runoff to drain out in 3 to 4 hours after storm even unless used for irrigation

SITE FACTORS

- Water Table/ Bedrock Separation: 2-foot minimum, 4-foot recommended (N/A for contained planter)
- Soils: HSG A and B preferred; C & D may require an underdrain (N/A for contained planter)
- Feasibility on steeper slopes: medium
- Potential Hotspots: yes with pretreatment and/or impervious liner, yes for contained planter
- Maximum recommended drainage area loading: 15:1; not more than 1 acre to one rain garden

MAINTENANCE

- Often requires watering during establishment
- Spot weeding, pruning, erosion repair, trash removal, mulch reapplication (as needed) required 2-3x/growing season
- Maintenance tasks and costs are similar to traditional landscaping

COST

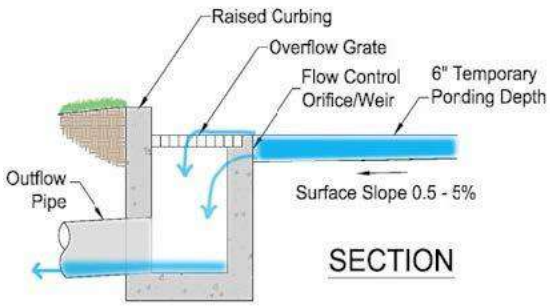
- Bioretention costs will vary depending on size/vegetation type/storage elements; typical costs $10-25/ sq. ft.

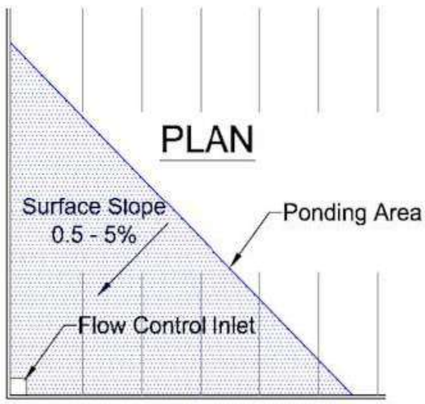
POTENTIAL LIMITATIONS

- Higher maintenance until vegetation is established
- Limited impervious drainage area to each BMP
- Requires careful selection & establishment of plants

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	High	TSS	High	Capital Cost	Medium
Groundwater Recharge	High	TP	High	Maintenance	Low/Medium
Peak Rate	Medium	TN	Medium	Winter Performance	Medium
Erosion Reduction	Medium	Temperature	Medium/High	Fast Track Potential	Medium
Flood Protection	Medium			Aesthetics	High

FACT SHEET: BLUE STREETS





Blue streets refer to the practice of temporarily detaining stormwater, delaying its release and reducing its peak flow rate into the storm sewer system.

Surface storage practices have been used traditionally on rooftops (i.e. blue roofs) and in parking lots but can also be implemented in residential streets and right-of-ways with lower traffic volumes. These "blue streets" can be a cost-effective way to manage stormwater and address surcharging without significant subsurface excavation and construction interventions.

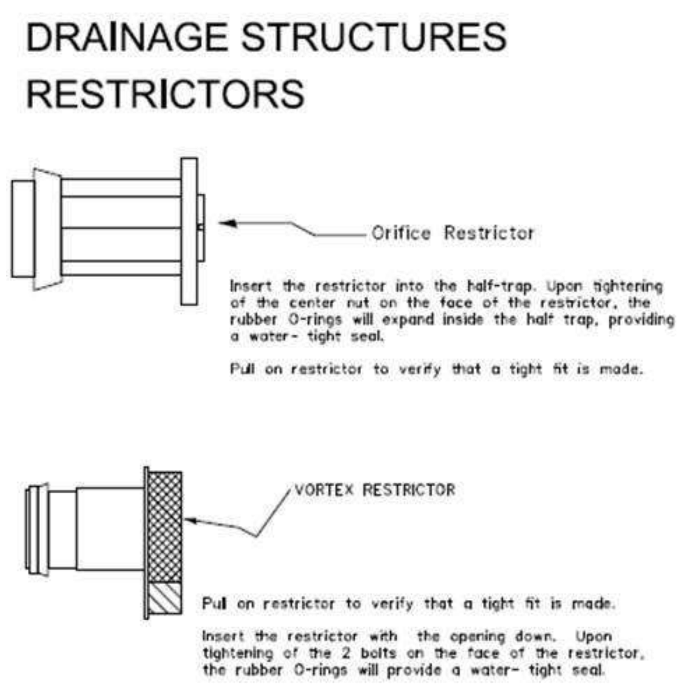
Surface storage is typically accomplished using drainage structures and retrofitting existing catch basins to feature devices such as orifice restrictors or vortex restrictors. Blue streets also emphasize minimizing the number of catch basins to the extent practical.

Blue streets (surface storage techniques) are often best implemented in alleys, low volume roads, and on private sites, for public perception and safety reasons.

BENEFITS

- Reduces stress on drainage system
- Mitigates peak rate flow
- Cost-effective technique to manage stormwater
- Short duration storage
- Reduces need for subsurface excavation and construction

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra-Urban	Limited
Industrial	Yes
Retrofit	Yes
Highway/Road	Limited for Highway
Recreational	Yes
Public/Private	Yes/Yes



Drainage structure restrictors are key features of surface storage and blue streets. Source: City of Chicago design manual

VARIATIONS

- Flow control structures
- Orifice restrictors
- Vortex restrictors
- Reduction in number of catch basins/inlets on a street

KEY DESIGN FEATURES

- Emergency overflows typically required
- Maximum ponding depths (less than one foot)
- Adequate surface slope to outlet
- Traffic volume, public safety, and user inconvenience must be taken into account

SITE FACTORS

- Water table to bedrock depth – N/A
- Soils – N/A
- Slope – Requires relatively low slopes to provide appreciable storage
- Potential hotspots – yes
- Maximum drainage area – relatively small DA to individual inlets (similar to conventional inlets)

MAINTENANCE

- Clean drainage structures and repair/replace parts as needed

COST

- Drainage structures restrictors range in cost, for example installing a vortex restrictor can be approximately $1000 per inlet

POTENTIAL LIMITATIONS

- Not suitable for heavily-used roadways without adequate median/shoulder space
- Excess ponding on roadways may freeze in winter conditions
- Public safety perceptions and concerns
- Does not inherently address water quality and quantity – should generally be combined with other BMPs

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Low	TSS	Low	Capital Cost	Low
Groundwater Recharge	Low	TP	Low	Maintenance	Low/Medium
Peak Rate	Medium	TN	Low	Winter Performance	Medium
Erosion Reduction	Low	Temperature	Low	Fast Track Potential	High
Flood Protection	Medium			Aesthetics	Low

FACT SHEET: CISTERNS/RAIN BARRELS

Example of above-ground cistern with vegetation screening

Cisterns (or rain barrels) are structures designed to intercept and store runoff from rooftops to allow for its reuse, reducing volume and overall water quality impairment. Stormwater is contained in the cistern structure and typically reused for irrigation or other water needs. This GI technology reduces potable water needs while also reducing stormwater discharges.

Cisterns can be located above or below ground and are containers or tanks with a larger storage capacity than a rain barrel, and often used to supplement grey water needs (i.e. toilet flushing) in a building, as well as irrigation. Rain barrels are above-ground structures connected to rooftop downspouts that collect rainwater and store it until needed for a specific use, such as landscape irrigation.

Cisterns and rain barrels can be used in suburban and urban areas where the need for supplemental onsite irrigation or other high water uses is especially apparent.

BENEFITS

- Provides supplemental water supply
- Wide applicability
- Reduces potable water use
- Related cost savings and environmental benefits
- Reduces stormwater runoff impacts

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra-Urban	Yes, if demand exists
Industrial	Yes
Retrofit	Yes
Highway/Road	No
Recreational	Limited
Public/Private	Yes/Yes

Rain barrel prototype example

VARIATIONS

- Cisterns – can be either underground and above ground
- Water storage tanks
- Storage beneath a usable surface using manufactured stormwater products (chambers, pipes, crates, etc.)
- Various sizes, materials, shapes, etc.

KEY DESIGN FEATURES

- Small storm events are captured with most structures
- Provide overflow for large storms events
- Discharge/use water before next storm event
- Consider site topography, placing structure upgradient of plantings (if applicable) in order to eliminate pumping needs

SITE FACTORS

- Water table to bedrock depth – N/A (although must be considered for subsurface systems)
- Soils – N/A
- Slope – N/A
- Potential hotspots – typically N/A for rooftop runoff
- Maximum drainage area – typically relatively small, based on storage capacity

MAINTENANCE

- Use stored water and/or discharge before next storm event
- Clean annually and check for loose valves, leaks, etc. monthly during active season
- May require flow bypass valves or be taken offline during the winter

COST

- Cisterns typically cost from $3 to $8/gallon/ Rain Barrels range from $75 to $300 each

POTENTIAL LIMITATIONS

- Manages only relatively small storm events which requires additional management and use for the stored water.
- Typically requires additional management of runoff
- Requires a use for the stored water (irrigation, gray water, etc.)

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Low/Medium	TSS	Medium	Capital Cost	Medium
Groundwater Recharge*	Low/Medium	TP	Medium	Maintenance	Medium
Peak Rate*	Low	TN	Low	Winter Performance	Low
Erosion Reduction	Low	Temperature	Low	Fast Track Potential	Medium/High
Flood Protection*	Low			Aesthetics	Low/Medium

**Although stand-alone cisterns are expected to have lower benefits in these categories, if combined with downspout disconnection to landscaped areas the benefits can be increased significantly.*

FACT SHEET: VEGETATED (GREEN) ROOFS AND BLUE ROOFS

Green roof (Philadelphia, PA)

Blue roof (NYC) / Photo – Gowanus Canal Conservancy

A green roof is a veneer of vegetation that is grown on and covers an otherwise conventional flat or pitched roof, endowing the roof with hydrologic characteristics that more closely match surface vegetation. The overall thickness of the veneer typically ranges from 2 to 6 inches and may contain multiple layers, such as waterproofing, synthetic insulation, non-soil engineered growth media, fabrics, and synthetic components. Vegetated roofs can be optimized to achieve water quantity and water quality benefits. Through the appropriate selection of materials, even thin vegetated covers can provide significant rainfall retention and detention functions.

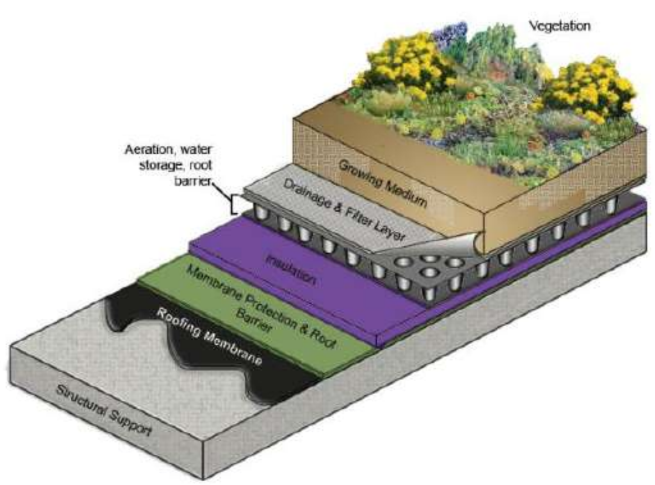
Depending on the plant material and planned usage for the roof area, modern vegetated roofs can be categorized as systems that are intensive (usually > 6 inches of substrate), semi-intensive, or extensive (<4 inches). More maintenance, higher costs and more weight are the characteristics for the intensive system compared to that of the extensive vegetated roof.

Another GI rooftop technology - **Blue roofs -** are non-vegetated systems that employ stormwater control devices to temporarily store water on the rooftop and then release it into the drainage system at a relatively low flow rate. Storage can be provided by modifying roof drains or through the use of detention trays that sometimes have a lightweight gravel media. Blue roof and green roof technologies can also be combined in a design to achieve

BENEFITS

- High volume reduction (annual basis)
- Moderate ecological value and habitat (green roofs)
- High aesthetic value (green roofs)
- Energy benefits (heating/cooling)
- Urban heat island reduction

POTENTIAL APPLICATIONS	
Residential	Limited
Commercial	Yes
Ultra-Urban	Yes
Industrial	Yes
Retrofit	Yes
Highway/Road	No
Recreational	Limited
Public/Private	Yes/Yes



Cross-section showing components of vegetated roof system

VARIATIONS

- Green roofs - single media system, dual media system (with synthetic liner)
- Green roofs - Intensive, Extensive, or Semi-intensive

KEY DESIGN FEATURES

- Engineered media should have a high mineral content and is typically 85% to 97% nonorganic.
- 2-6 inches of non-soil engineered media; assemblies that are 4 inches and deeper may include more than one type of engineered media.
- Irrigation is generally not required (or even desirable) for optimal stormwater management
- Internal building drainage, including provision to cover and protect deck drains or scuppers, must anticipate the need to manage large rainfall events without inundating the vegetated roof system.
- Assemblies planned for roofs with pitches steeper than 2:12 (9.5 degrees) must incorporate supplemental measures to insure stability against siding.
- The roof structure must be evaluated for compatibility with the maximum predicted dead and live loads. Typical dead loads for wet extensive vegetated covers range from about 12 to 36 pounds per square foot.
- Waterproofing must be resistant to biological and root attack. In many instances a supplemental root barrier-layer is installed to protect the primary waterproofing.
- Blue roofs: roof structure, waterproofing, accommodation for larger storm events/emergency overflows

MAINTENANCE

- Once vegetation is fully established, little maintenance needed for the extensive system
- Maintenance cost is similar to native landscaping, $0.10-$0.35 per square foot
- Blue roof maintenance is similar to conventional roof maintenance (cleaning roof and drains as necessary)

COST

- Green roofs: $10 - $35 per square foot, including all structural components, soil, and plants; more expensive than traditional roofs, but have longer lifespan; generally less expensive to install on new roof versus retrofit on existing roof
- Blue roofs: Typically add only $1-$5 per square foot compared to traditional roofs

POTENTIAL LIMITATIONS

- Green roofs have higher maintenance needs until vegetation is established
- Need for adequate roof structure and waterproofing; can be challenging on retrofit application

STORMWATER QUANTITY FUNCTIONS*		STORMWATER QUALITY FUNCTIONS*		ADDITIONAL CONSIDERATIONS	
Volume	Medium/High	TSS	Low/Medium	Capital Cost	High
Groundwater Recharge	Low	TP	Low/Medium	Maintenance	Medium
Peak Rate	Medium	TN	Low	Winter Performance	Medium
Erosion Reduction	Low/Medium	Temperature	Medium	Fast Track Potential	Low
Flood Protection	Low/Medium			Aesthetics	High

**For green roofs, blue roofs primarily function for peak rate control and flood protection.*

FACT SHEET: POROUS PAVEMENT

Porous asphalt basketball courts (Lancaster, PA)

Porous (pervious) pavement is a Green Infrastructure (GI) technique that combines stormwater infiltration, storage, and a structural pavement consisting of a permeable surface underlain by a storage/infiltration bed. Porous pavement is well suited for parking areas, walking paths, sidewalks, playgrounds, plazas, basketball courts, and other similar uses.

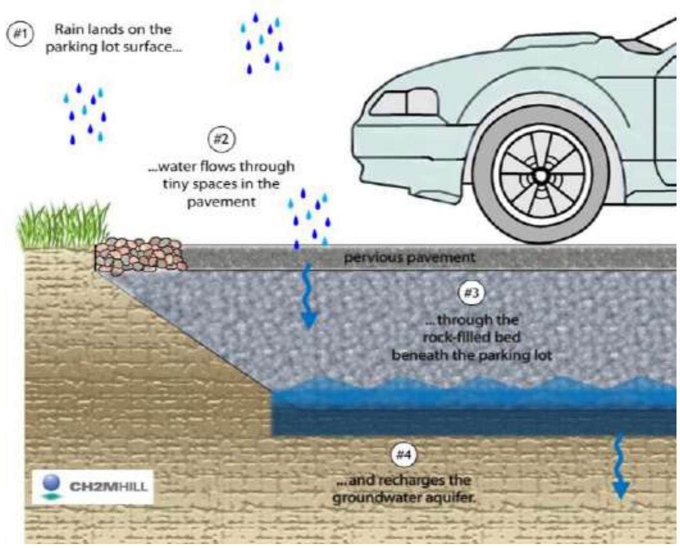
A porous pavement system consists of a pervious surface course underlain by a storage bed, typically placed on uncompacted subgrade to facilitate stormwater infiltration. The subsurface storage reservoir may consist of a stone bed of uniformly graded, clean and washed course aggregate with a void space of approximately 40% or other manufactured structural storage units. Porous pavement may be asphalt, concrete, permeable paver blocks, reinforced turf/gravel, or other emerging types of pavement.

BENEFITS

- Volume control & GW recharge, moderate peak rate control
- Versatile with broad applicability
- Dual use for pavement structure and stormwater management
- Pavers come in range of sizes and colors
- Opportunity for public education/demonstration

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra Urban	Yes
Industrial	Limited
Retrofit	Yes
Highway	Limited
Recreational	Yes
Public/Private	Yes/Yes

Porous pavers (San Diego)



Conceptual diagram showing how porous pavement functions

KEY DESIGN FEATURES

- Soil testing required for infiltration designs
- Limit amount of adjacent areas that drain directly onto the surface of the porous pavement
- Uncompacted soil subgrade for infiltration
- Level storage bed bottoms
- Provide positive storm water overflow from bed
- Surface permeability greater than 20 inches per hour
- Secondary inflow mechanism recommended
- Pretreatment for sediment-laden runoff, limit sources of sediment/debris deposition

SITE FACTORS

- Water Table/Bedrock Separation: 2-foot minimum
- Soils: HSG A&B preferred; HSG C&D may require underdrains
- Feasibility on steeper slopes: Low
- Potential Hotspots: Not without design of pretreatment system/impervious liner

MAINTENANCE

- Clean inlets
- Vacuum biannually
- Maintain adjacent landscaping/planting beds
- Periodic replacement of aggregate in paver block joints (if applicable)
- Careful winter maintenance (no sand or other abrasives, careful plowing)

COST

- Varies by porous pavement type
- Local quarry needed for stone filled infiltration bed
- Typically $7-$15 per square foot, including underground stormwater storage bed
- Generally more than standard pavement, but saves on cost of other BMPs and traditional drainage infrastructure

POTENTIAL LIMITATIONS

- Careful design & construction required
- Pervious pavement not suitable for all uses/not suitable for steep slopes
- Higher maintenance needs than standard pavement

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	High	TSS*	High	Capital Cost	Medium
Groundwater Recharge	High	TP	High	Maintenance	Medium
Peak Rate	Medium/High	TN	Medium	Winter Performance	Medium/High
Erosion Reduction	Medium/High	Temperature	High	Fast Track Potential	Low/Medium
Flood Protection	Medium/High			Aesthetics	Low to High

** While porous pavements typically result in low TSS loads, sources of sediment should be minimized to reduce the risk of clogging.*

FACT SHEET: SOIL AMENDMENTS

Healthy soils help vegetation thrive while also increasing soil infiltration rates Photo: S.Coronado

Soil amendments can include a variety of practices that reduce the generation of runoff by improving vegetation growth, increasing water infiltration, and improving water holding capacity. For example, on existing turf grass, soil amendments can include placing a thin layer of compost or other materials and spreading them evenly over existing vegetation. Amendments on existing turf grass areas can be applied for several years to improve soil over time. Soil testing can indicate how many applications are appropriate. Existing grass areas can also be aerated to improve water transmission and allow for deeper incorporation of compost.

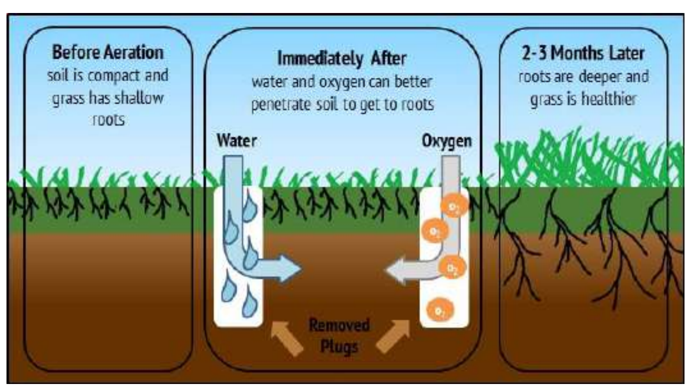
On new construction, redevelopment, and restoration projects, compost can be applied and deeply tilled into compacted soils to restore their porosity before the areas are re-vegetated (potentially with native landscaping, combining the benefits of both GI strategies).

BENEFITS

- Enhanced soil health and vegetation growth/root depth
- Improved soil infiltration rates
- Enhanced soil water holding capacity
- Reduced stormwater runoff from soil surface

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra-Urban	Limited
Industrial	Yes
Retrofit	Yes
Highway/Road	Yes
Recreational	Yes
Public/Private	Yes/Yes

A variety of soil amendments are available depending on the specific soil conditions and desired result. Photo: Pahls Market



Physical aeration (tilling) can also help improve soil health and soil permeability/porosity. Image: GreenMaxLawns

VARIATIONS

- Treating turf grass or areas with more intensive plant palettes
- Combining amended soil areas with downspout disconnection
- Physical aeration/tilling of turf grass/vegetated areas can help to remedy soil compaction
- Compost, sand, microbes, mycorrhizae, gypsum, biochar, manure, worm castings, etc.
- Amendments can improve soil aggregation, increase porosity, and improve aeration and rooting depth

KEY DESIGN FEATURES

- Soil bulk density and soil nutrient testing required
- Existing soil conditions should be evaluated before forming an amendment strategy

SITE FACTORS

- Water table to bedrock depth – N/A
- Soils – Bulk density and nutrient levels
- Slope – Not recommended for use on slopes greater than 3:1
- Potential hotspots – N/A
- Maximum drainage area – N/A

MAINTENANCE

- Replenishment of amendments on a regular basis may be required
- Aeration of soil often done at same time

COST

- The cost of soil amendments ranges widely depending on the size and type. Larger projects are estimated to cost approximately $5,000 per acre.

POTENTIAL LIMITATIONS

- Viability depends upon soil testing results
- Certain types of soil may not be favorable for success with amendments
- Not a regulated industry – testing of amendment may be needed to ensure specifications
- Physical aeration should not be done near existing tree roots

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Medium	TSS*	Medium	Capital Cost	Low
Groundwater Recharge	Medium	TP*	Medium	Maintenance	Low/Medium
Peak Rate	Medium	TN*	Medium	Winter Performance	Medium
Erosion Reduction	High	Temperature	Low	Fast Track Potential	Medium
Flood Protection	Low/Medium			Aesthetics	Medium

**Water quality benefits expected to vary widely depending on the condition of the soil/landscape prior to soil amendments.*

Appendix E
Alternatives Analysis Results

Appendix E - Alternative Analysis Summary

Tabulation of solutions, costs, and scoring for all projects

		Solution Summary			Flood Volume Summary					Weighted Solution Score								
Problem Area ID	Solution Technology (Conveyance, Storage, Low GI, Medium GI, High GI)	Project Name	Cost ($M)	Benefit-Cost Ratio	Existing Flood Volume (MG)	Solution Flood Volume (MG)	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)	Urban Drainage/ Flooding	Environmental Compliance	EcoCity Goals/ Sustainability	Social Benefits	Integrated Asset Management	City-Wide Maintenance Implications	Constructability	Public Acceptance	Total
1	Conveyance	CONV-1	$ 2.352	16.4	0.35	0.06	0.29	82%	$ 8.08	8.7	0.0	0.0	0.0	6.6	16.2	2.2	4.8	38.5
1	Storage	STOR-1	$ 0.345	70.8	0.35	0.11	0.25	70%	$ 1.38	12.0	0.0	0.0	0.0	0.0	3.2	4.3	4.8	24.4
1	Low GI	LGI-1	$ 0.087	539.5	0.35	0.32	0.04	10%	$ 2.37	1.8	2.5	4.1	3.3	6.6	13.0	10.8	4.8	46.9
1	Medium GI	MGI-1	$ 0.504	112.5	0.35	0.22	0.13	37%	$ 3.86	6.3	7.7	4.1	3.3	6.6	13.0	10.8	4.8	56.6
1	High GI	HGI-1	$ 1.444	45.5	0.35	0.14	0.21	59%	$ 6.85	10.2	12.9	4.1	3.3	6.6	13.0	10.8	4.8	65.7
2	Conveyance	CONV-2	$ 0.634	47.0	1.02	0.83	0.19	18%	$ 3.36	0.0	0.0	0.0	0.0	6.6	16.2	2.2	4.8	29.8
2	Storage	STOR-2	$ 1.293	8.6	1.02	0.97	0.05	5%	$ 24.60	0.9	0.0	0.0	0.0	0.0	3.2	2.2	4.8	11.1
2	Low GI	LGI-2	$ 0.046	996.0	1.02	0.97	0.06	5%	$ 0.81	0.9	2.5	3.8	3.0	6.6	13.0	10.8	4.8	45.4
2	Medium GI	MGI-2	$ 0.263	198.8	1.02	0.86	0.16	16%	$ 1.60	2.8	7.5	3.8	3.0	6.6	13.0	10.8	4.8	52.2
2	High GI	HGI-2	$ 0.752	78.5	1.02	0.76	0.26	26%	$ 2.86	4.4	12.6	3.8	3.0	6.6	13.0	10.8	4.8	59.0
3	Conveyance	CONV-3	$ 1.272	41.4	1.25	0.27	0.97	78%	$ 1.31	13.4	0.0	0.0	2.9	13.2	16.2	2.2	4.8	52.6
3	Storage	STOR-3	$ 2.273	15.0	1.25	0.68	0.57	45%	$ 4.01	7.8	0.0	0.0	2.9	13.2	3.2	2.2	4.8	34.1
3	Low GI	LGI-3	$ 0.237	207.2	1.25	1.17	0.07	6%	$ 3.20	1.0	2.9	4.6	5.2	13.2	13.0	4.3	4.8	49.1
3	Medium GI	MGI-3	$ 1.370	41.8	1.25	1.02	0.23	19%	$ 5.92	3.2	9.0	4.6	5.2	13.2	13.0	4.3	4.8	57.3
3	High GI	HGI-3	$ 3.932	16.7	1.25	0.87	0.38	31%	$ 10.31	5.2	15.3	4.6	5.2	13.2	13.0	4.3	4.8	65.7
4	Conveyance	CONV-4	$ 3.644	8.2	2.91	2.22	0.69	24%	$ 5.26	0.0	0.0	0.0	0.0	6.6	16.2	2.2	4.8	29.8
4	Storage	STOR-4	$ 1.010	12.8	2.91	2.44	0.47	16%	$ 2.15	2.8	0.0	0.0	0.0	0.0	3.2	2.2	4.8	13.0
4	Low GI	LGI-4	$ 0.383	116.7	2.91	2.78	0.13	4%	$ 3.06	0.7	2.2	3.6	2.9	6.6	13.0	10.8	4.8	44.7
4	Medium GI	MGI-4	$ 2.219	22.8	2.91	2.55	0.36	12%	$ 6.20	2.1	6.7	3.6	2.9	6.6	13.0	10.8	4.8	50.6
4	High GI	HGI-4	$ 6.368	8.9	2.91	2.31	0.60	21%	$ 10.63	3.5	11.3	3.6	2.9	6.6	13.0	10.8	4.8	56.5
5	Conveyance	CONV-5	$ 0.718	56.2	1.28	-	1.28	100%	$ 0.56	17.1	0.0	0.0	0.0	0.0	16.2	2.2	4.8	40.3
5	Storage	STOR-5	$ 2.242	11.7	1.28	0.08	1.20	94%	$ 1.87	16.1	0.0	0.0	0.0	0.0	3.2	2.2	4.8	26.3
5	Low GI	LGI-5	$ 0.101	364.7	1.28	1.24	0.04	3%	$ 2.51	0.5	2.1	3.1	2.5	6.6	13.0	4.3	4.8	36.9
5	Medium GI	MGI-5	$ 0.584	73.4	1.28	1.11	0.17	13%	$ 3.41	2.3	6.3	3.1	2.5	6.6	13.0	4.3	4.8	42.9
5	High GI	HGI-5	$ 1.672	29.1	1.28	1.00	0.29	22%	$ 5.86	3.8	10.6	3.1	2.5	6.6	13.0	4.3	4.8	48.7
6	Conveyance	CONV-6	$ 1.841	19.1	2.25	1.14	1.11	49%	$ 1.66	5.3	0.0	0.0	0.0	6.6	16.2	2.2	4.8	35.1
6	Storage	STOR-6	$ 2.300	9.4	2.25	1.02	1.23	54%	$ 1.88	9.3	0.0	0.0	0.0	0.0	3.2	4.3	4.8	21.7
6	Low GI	LGI-6	$ 0.146	309.8	2.25	2.11	0.14	6%	$ 1.07	1.0	2.6	3.6	2.9	6.6	13.0	10.8	4.8	45.3
6	Medium GI	MGI-6	$ 0.848	62.3	2.25	1.82	0.43	19%	$ 1.96	3.3	7.9	3.6	2.9	6.6	13.0	10.8	4.8	52.8
6	High GI	HGI-6	$ 2.432	24.8	2.25	1.54	0.71	31%	$ 3.44	5.4	13.2	3.6	2.9	6.6	13.0	10.8	4.8	60.2
7	Conveyance	CONV-7	$ 1.473	15.7	0.29	0.01	0.28	97%	$ 5.24	0.0	0.0	0.0	0.0	0.0	16.2	2.2	4.8	23.2
7	Storage	STOR-7	$ 0.995	14.8	0.29	0.21	0.08	27%	$ 12.90	4.6	0.0	0.0	0.0	0.0	3.2	2.2	4.8	14.8
7	Low GI	LGI-7	$ 0.071	449.0	0.29	0.28	0.01	5%	$ 4.72	0.9	2.2	3.6	2.9	0.0	13.0	4.3	4.8	31.7
7	Medium GI	MGI-7	$ 0.409	93.1	0.29	0.24	0.05	16%	$ 8.85	2.7	6.7	3.6	2.9	0.0	13.0	4.3	4.8	38.0
7	High GI	HGI-7	$ 1.172	37.9	0.29	0.21	0.08	27%	$ 14.89	4.7	11.2	3.6	2.9	0.0	13.0	4.3	4.8	44.5
8	Conveyance	CONV-8	$ 3.284	7.7	0.13	2.33	N/A	-1647%	N/A	0.0	0.0	0.0	0.0	0.0	16.2	4.3	4.8	25.4
8	Storage	STOR-8	$ 0.113	137.8	0.13	0.09	0.04	31%	$ 2.71	5.4	0.0	0.0	0.0	0.0	3.2	2.2	4.8	15.6
8	Low GI	LGI-8	$ 0.438	106.2	0.13	0.11	0.02	15%	$ 22.16	2.5	2.3	3.6	2.9	6.6	13.0	10.8	4.8	46.5
8	Medium GI	MGI-8	$ 2.540	22.2	0.13	0.07	0.06	45%	$ 42.46	7.7	6.8	3.6	2.9	6.6	13.0	10.8	4.8	56.3
8	High GI	HGI-8	$ 7.288	9.0	0.13	0.04	0.10	73%	$ 75.41	12.5	11.4	3.6	2.9	6.6	13.0	10.8	4.8	65.6
9	Conveyance	CONV-9	$ 0.160	265.9	0.00	-	0.00	100%	$ 56.95	17.1	0.0	0.0	0.0	0.0	16.2	4.3	4.8	42.5
9	Low GI	LGI-9	$ 0.771	78.0	0.00	0.00	0.00	93%	$ 294.28	16.0	2.1	3.8	3.1	6.6	13.0	10.8	4.8	60.2
9	Medium GI	MGI-9	$ 4.476	14.6	0.00	0.00	0.00	99%	$ 1,603.67	17.0	6.4	3.8	3.1	6.6	13.0	10.8	4.8	65.5
9	High GI	HGI-9	$ 12.841	5.5	0.00	-	0.00	100%	$ 4,573.68	17.1	10.8	3.8	3.1	6.6	13.0	10.8	4.8	70.0
10	Conveyance	CONV-10	$ 0.848	37.3	0.39	0.12	0.27	68%	$ 3.15	8.5	0.0	0.0	0.0	0.0	16.2	2.2	4.8	31.7
10	Storage	STOR-10	$ 1.035	20.3	0.39	0.20	0.20	50%	$ 5.23	8.6	0.0	0.0	0.0	0.0	3.2	4.3	4.8	21.0
10	Low GI	LGI-10	$ 0.170	270.7	0.39	0.34	0.05	13%	$ 3.44	2.1	2.4	3.4	2.8	6.6	13.0	10.8	4.8	45.9
10	Medium GI	MGI-10	$ 0.979	55.5	0.39	0.26	0.14	34%	$ 7.25	5.9	7.1	3.4	2.8	6.6	13.0	10.8	4.8	54.4
10	High GI	HGI-10	$ 2.810	22.0	0.39	0.20	0.20	50%	$ 14.21	8.6	11.9	3.4	2.8	6.6	13.0	10.8	4.8	61.9
11	Conveyance	CONV-11	$ 0.787	54.0	0.38	-	0.38	100%	$ 2.09	17.1	0.0	0.0	0.0	0.0	16.2	4.3	4.8	42.5
11	Storage	STOR-11	$ 0.337	52.0	0.38	0.26	0.11	30%	$ 2.96	5.2	0.0	0.0	0.0	0.0	3.2	4.3	4.8	17.5
11	Low GI	LGI-11	$ 0.078	415.1	0.38	0.34	0.04	10%	$ 2.09	1.7	2.1	3.6	2.9	0.0	13.0	4.3	4.8	32.4
11	Medium GI	MGI-11	$ 0.452	88.8	0.38	0.26	0.11	30%	$ 3.96	5.2	6.3	3.6	2.9	0.0	13.0	4.3	4.8	40.1
11	High GI	HGI-11	$ 1.294	36.9	0.38	0.19	0.19	50%	$ 6.81	8.7	10.5	3.6	2.9	0.0	13.0	4.3	4.8	47.8
12	Conveyance	CONV-12	$ 0.283	158.0	0.14	0.07	0.07	48%	$ 4.13	8.3	0.0	0.0	0.0	13.2	16.2	2.2	4.8	44.7
12	Storage	STOR-12	$ 0.491	65.7	0.14	0.01	0.13	90%	$ 3.85	15.4	0.0	0.0	0.0	6.6	3.2	2.2	4.8	32.2
12	Low GI	LGI-12	$ 0.076	671.0	0.14	0.13	0.01	8%	$ 6.68	1.4	3.0	6.2	5.0	13.2	13.0	4.3	4.8	50.9
12	Medium GI	MGI-12	$ 0.439	140.4	0.14	0.09	0.05	34%	$ 9.18	5.8	9.3	6.2	5.0	13.2	13.0	4.3	4.8	61.6

Appendix E - Alternative Analysis Summary

Tabulation of solutions, costs, and scoring for all projects

		Solution Summary			Flood Volume Summary					Weighted Solution Score								
Problem Area ID	Solution Technology (Conveyance, Storage, Low GI, Medium GI, High GI)	Project Name	Cost ($M)	Benefit-Cost Ratio	Existing Flood Volume (MG)	Solution Flood Volume (MG)	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)	Urban Drainage/ Flooding	Environmental Compliance	EcoCity Goals/ Sustainability	Social Benefits	Integrated Asset Management	City-Wide Maintenance Implications	Constructability	Public Acceptance	Total
12	High GI	HGI-12	$ 1.259	57.9	0.14	0.06	0.09	61%	$ 14.57	10.5	15.9	6.2	5.0	13.2	13.0	4.3	4.8	72.8
13	Conveyance	CONV-13	$ 1.011	39.0	0.91	0.02	0.90	98%	$ 1.13	14.0	0.0	0.0	0.0	0.0	16.2	4.3	4.8	39.4
13	Low GI	LGI-13	$ 0.332	137.5	0.91	0.86	0.06	6%	$ 5.91	1.1	2.5	3.8	3.1	6.6	13.0	10.8	4.8	45.7
13	Medium GI	MGI-13	$ 1.927	27.7	0.91	0.73	0.19	20%	$ 10.36	3.5	7.7	3.8	3.1	6.6	13.0	10.8	4.8	53.3
13	High GI	HGI-13	$ 5.530	11.1	0.91	0.58	0.33	37%	$ 16.61	6.3	13.0	3.8	3.1	6.6	13.0	10.8	4.8	61.4
14	Conveyance	CONV-14	$ 0.137	281.3	0.18	0.02	0.16	90%	$ 0.84	15.4	0.0	0.0	0.0	0.0	16.2	2.2	4.8	38.6
14	Low GI	LGI-14	$ 0.027	1149.9	0.18	0.17	0.01	6%	$ 2.34	1.1	2.2	3.2	2.6	0.0	13.0	4.3	4.8	31.1
14	Medium GI	MGI-14	$ 0.158	239.8	0.18	0.14	0.04	20%	$ 4.26	3.5	6.6	3.2	2.6	0.0	13.0	4.3	4.8	37.9
14	High GI	HGI-14	$ 0.453	99.6	0.18	0.12	0.07	36%	$ 6.87	6.2	11.0	3.2	2.6	0.0	13.0	4.3	4.8	45.1
15	Conveyance	CONV-15	$ 0.518	91.5	0.41	0.01	0.40	97%	$ 1.29	12.6	0.0	0.0	2.9	6.6	16.2	4.3	4.8	47.4
15	Storage	STOR-15	$ 0.847	50.2	0.41	0.07	0.34	82%	$ 2.49	14.1	0.0	0.0	2.9	13.2	3.2	4.3	4.8	42.5
15	Low GI	LGI-15	$ 0.057	768.7	0.41	0.40	0.02	4%	$ 3.14	0.8	3.2	5.6	5.9	6.6	13.0	4.3	4.8	44.2
15	Medium GI	MGI-15	$ 0.332	165.1	0.41	0.30	0.11	27%	$ 3.00	4.6	10.0	5.6	5.9	6.6	13.0	4.3	4.8	54.8
15	High GI	HGI-15	$ 0.952	68.0	0.41	0.23	0.19	45%	$ 5.09	7.7	16.8	5.6	5.9	6.6	13.0	4.3	4.8	64.7
16	Conveyance	CONV-16	$ 0.865	42.3	0.62	-	0.62	100%	$ 1.39	11.3	0.0	0.0	0.0	0.0	16.2	4.3	4.8	36.6
16	Storage	STOR-16	$ 0.393	43.0	0.62	0.38	0.24	39%	$ 1.63	6.7	0.0	0.0	0.0	0.0	3.2	2.2	4.8	16.9
16	Low GI	LGI-16	$ 0.070	638.5	0.62	0.59	0.03	4%	$ 2.52	0.8	2.0	3.6	2.9	6.6	13.0	10.8	4.8	44.4
16	Medium GI	MGI-16	$ 0.405	123.8	0.62	0.53	0.09	14%	$ 4.54	2.5	5.9	3.6	2.9	6.6	13.0	10.8	4.8	50.1
16	High GI	HGI-16	$ 1.159	48.4	0.62	0.46	0.16	26%	$ 7.13	4.5	9.9	3.6	2.9	6.6	13.0	10.8	4.8	56.1
17	Conveyance	CONV-17	$ 0.417	94.7	0.04	0.01	0.03	83%	$ 14.40	14.2	0.0	0.0	0.0	0.0	16.2	4.3	4.8	39.5
17	Storage	STOR-17	$ 0.403	59.1	0.04	0.01	0.02	67%	$ 17.19	11.5	0.0	0.0	0.0	0.0	3.2	4.3	4.8	23.8
17	Low GI	LGI-17	$ 0.046	922.1	0.04	0.02	0.01	29%	$ 4.51	5.0	2.6	3.7	2.9	0.0	13.0	10.8	4.8	42.8
17	Medium GI	MGI-17	$ 0.270	208.3	0.04	0.01	0.03	77%	$ 9.94	13.3	7.8	3.7	2.9	0.0	13.0	10.8	4.8	56.2
17	High GI	HGI-17	$ 0.774	84.4	0.04	0.00	0.04	100%	$ 22.11	17.1	13.0	3.7	2.9	0.0	13.0	10.8	4.8	65.3
18	Conveyance	CONV-18	$ 0.169	215.7	0.20	0.30	N/A	-52%	N/A	0.0	0.0	0.0	0.0	13.2	16.2	2.2	4.8	36.4
18	Storage	STOR-18	$ 0.330	65.0	0.20	0.07	0.13	66%	$ 2.58	11.3	0.0	0.0	0.0	0.0	3.2	2.2	4.8	21.5
18	Low GI	LGI-18	$ 0.045	901.8	0.20	0.17	0.02	13%	$ 1.79	2.2	2.8	3.7	3.0	6.6	13.0	4.3	4.8	40.4
18	Medium GI	MGI-18	$ 0.259	195.3	0.20	0.12	0.08	39%	$ 3.40	6.7	8.4	3.7	3.0	6.6	13.0	4.3	4.8	50.5
18	High GI	HGI-18	$ 0.743	81.7	0.20	0.07	0.13	65%	$ 5.90	11.1	14.2	3.7	3.0	6.6	13.0	4.3	4.8	60.6
19	Conveyance	CONV-19	$ 0.994	25.5	0.00	0.46	N/A	-82432%	N/A	0.0	0.0	0.0	0.0	0.0	16.2	4.3	4.8	25.4
19	Storage	STOR-19	$ 0.099	274.9	0.00	0.00	0.00	99%	$ 177.63	16.9	0.0	0.0	0.0	0.0	3.2	2.2	4.8	27.1
19	Low GI	LGI-19	$ 0.232	213.2	0.00	0.00	0.00	24%	$ 1,699.73	4.2	2.6	4.2	3.3	6.6	13.0	10.8	4.8	49.5
19	Medium GI	MGI-19	$ 1.347	45.2	0.00	0.00	0.00	60%	$ 3,992.31	10.3	7.9	4.2	3.3	6.6	13.0	10.8	4.8	60.9
19	High GI	HGI-19	$ 3.865	17.9	0.00	0.00	0.00	76%	$ 9,064.62	13.0	13.3	4.2	3.3	6.6	13.0	10.8	4.8	69.0
20	Conveyance	CONV-20	$ 0.166	255.6	0.04	-	0.04	100%	$ 4.44	17.1	0.0	0.0	0.0	0.0	16.2	4.3	4.8	42.5
20	Low GI	LGI-20	$ 0.021	1889.5	0.04	0.03	0.00	9%	$ 6.22	1.5	2.2	3.6	2.9	0.0	13.0	10.8	4.8	38.9
20	Medium GI	MGI-20	$ 0.119	390.0	0.04	0.03	0.01	26%	$ 12.27	4.4	6.8	3.6	2.9	0.0	13.0	10.8	4.8	46.4
20	High GI	HGI-20	$ 0.341	156.6	0.04	0.02	0.01	40%	$ 22.99	6.8	11.5	3.6	2.9	0.0	13.0	10.8	4.8	53.4
21	Conveyance	CONV-21	$ 0.250	186.2	0.13	0.00	0.12	98%	$ 2.03	16.8	0.0	0.0	0.0	6.6	16.2	2.2	4.8	46.6
21	Storage	STOR-21	$ 0.446	53.0	0.13	0.08	0.05	40%	$ 8.89	6.8	0.0	0.0	0.0	6.6	3.2	2.2	4.8	23.6
21	Low GI	LGI-21	$ 0.031	1105.3	0.13	0.11	0.01	9%	$ 2.87	1.5	2.6	1.0	0.8	6.6	13.0	4.3	4.8	34.6
21	Medium GI	MGI-21	$ 0.182	242.3	0.13	0.08	0.04	33%	$ 4.37	5.7	7.9	1.0	0.8	6.6	13.0	4.3	4.8	44.1
21	High GI	HGI-21	$ 0.522	100.8	0.13	0.06	0.06	51%	$ 8.09	8.8	13.4	1.0	0.8	6.6	13.0	4.3	4.8	52.7
22	Conveyance	CONV-22	$ 0.164	141.9	0.36	0.43	N/A	-19%	N/A	0.0	0.0	0.0	0.0	0.0	16.2	2.2	4.8	23.2
22	Storage	STOR-22	$ 0.255	79.5	0.36	0.19	0.17	46%	$ 1.53	7.9	0.0	0.0	0.0	0.0	3.2	4.3	4.8	20.3
22	Low GI	LGI-22	$ 0.020	2386.3	0.36	0.34	0.02	6%	$ 0.86	1.1	2.7	4.7	3.7	6.6	13.0	10.8	4.8	47.4
22	Medium GI	MGI-22	$ 0.116	486.8	0.36	0.27	0.10	26%	$ 1.21	4.5	8.3	4.7	3.7	6.6	13.0	10.8	4.8	56.4
22	High GI	HGI-22	$ 0.333	194.7	0.36	0.21	0.15	42%	$ 2.16	7.3	13.9	4.7	3.7	6.6	13.0	10.8	4.8	64.8
23	Conveyance	CONV-23	$ 0.201	225.4	0.42	0.09	0.34	80%	$ 0.60	10.4	0.0	0.0	2.9	6.6	16.2	4.3	4.8	45.2
23	Storage	STOR-23	$ 0.596	52.8	0.42	0.13	0.29	69%	$ 2.06	11.8	0.0	0.0	2.9	6.6	3.2	2.2	4.8	31.5
23	Low GI	LGI-23	$ 0.056	1024.0	0.42	0.37	0.05	11%	$ 1.16	2.0	3.1	4.8	5.3	13.2	13.0	10.8	4.8	56.9
23	Medium GI	MGI-23	$ 0.323	207.0	0.42	0.28	0.14	32%	$ 2.37	5.6	9.5	4.8	5.3	13.2	13.0	10.8	4.8	66.9
23	High GI	HGI-23	$ 0.926	83.0	0.42	0.20	0.22	52%	$ 4.21	8.9	16.0	4.8	5.3	13.2	13.0	10.8	4.8	76.8

Appendix F
Basis of Cost

City of Alexandria Storm Sewer Capacity Analysis

Planning Level Cost Information

PREPARED FOR:	City of Alexandria Transportation and Engineering Services
COPY TO:	File
PREPARED BY:	CH2M HILL
DATE:	May 15, 2014
PROJECT NUMBER:	240027

Introduction

The City of Alexandria, Virginia, has experienced repeated and increasingly frequent flooding events attributable to old infrastructure, inconsistent design criteria, and perhaps climate change. The purpose of the stormwater capacity analysis project is to provide a program for analyzing storm sewer capacity issues, identifying problem areas, developing and prioritizing solutions, and providing support for public outreach and education. The project is being implemented in phases by watershed. The watersheds include Hooffs Run, Four Mile Run, Holmes Run, Cameron Run, Taylor Run, Strawberry Run, Potomac River, and Backlick Run.

This technical memorandum provides details on the basis of cost estimates developed for each solution and the watershed wide alternatives. The information includes panning level unit cost for conveyance, storage and green infrastructure solutions.

These cost estimates are considered a Class 4 - Planning Level estimate as defined by the American Association of Cost Engineering (AACE), International Recommended Practice No. 18R-97, and as designated in ASTM E 2516-06. It is considered accurate to +50% to -30% based up to a 15% complete project definition.

Definitions

The following cost terminologies are used within this technical memorandum:

- Construction cost: Installed cost, including materials, labor, and site adjustment factors such as overcoming utility conflicts, dewatering, and pavement restoration.
- ENRCCI Cost Adjustment Factor: Cost adjustment factor of 0.9 to adjust cost to October 2013 dollars for the DC-Baltimore metro area
- Service and Contingency Factor (SCF): A factor of 1.4 is applied for this project to account for engineering and design expenses (20%) and for contingency allowance (20%).
- Capital cost: Construction cost multiplied by a Service and Contingency Factor (SCF) to cover engineering and design and contingency allowance.
- Operating cost: Operation and maintenance were not considered for this project.

Gravity Sewer Relief Costs

Conveyance projects were costed on a per linear foot basis, based on pipe size and depth. The construction cost rates ($/ft) for gravity sewer replacement are listed in Table 1. Cost rates are shown for different road types. The Gravity sewer cost rates include complete installation of sewer pipes, inlets/manholes, and other ancillary structures as well as surface restoration. The costs were established through literature review and updated based on an assessment of bid tabulation data from Kansas City metro area between 2008 and 2012, and a comparison to Fairfax County, VA unit cost schedule, March 2013. All costs were adjusted to Washington DC, 2013 dollars using Engineering News-Record Construction Cost Index (ENRCCI) adjustment factors.

Factors are applied to the construction cost of gravity sewer pipe replacement to reflect the cost associated with crossing under streams and railroads as listed in Table 2.

Costs of routine O&M, inspection and cleaning at periodic intervals during the life of the gravity sewer were assumed to part of City-wide facilities maintenance plan and should take place even though those costs are not specifically included here.

TABLE 1
Open Cut Gravity Sewer Construction Costs

		Sewer Construction Cost ($/LF) (1)					
		Trench depth up to 10 feet		Trench depth 10 to 15 feet		Trench depth 15 to 20 feet	
Pipe Diameter (in)	Material	Residential	Arterial	Residential	Arterial	Residential	Arterial
8	PVC	$90	$104	$113	$130	$140	$162
10	PVC	$113	$131	$140	$163	$176	$204
12	PVC	$122	$140	$152	$175	$190	$218
15	PVC	$131	$153	$163	$192	$204	$239
18	PVC	$140	$162	$175	$203	$218	$253
21	PVC	$162	$189	$203	$237	$253	$295
24	PVC	$185	$212	$230	$265	$288	$330
30	RCP	$257	$297	$320	$372	$401	$464
36	RCP	$306	$356	$383	$445	$478	$555
42	RCP	$360	$414	$450	$518	$563	$647
48	RCP	$410	$473	$512	$590	$640	$738
54	RCP	$459	$531	$574	$664	$717	$830
60	RCP	$509	$585	$635	$732	$795	$914
72	RCP	$815	$936	$1,018	$1,170	$1,273	$1,463

(1) Listed construction costs have been adjusted to October 2013 dollars using ENRCCI for the DC-Baltimore Metro area.

TABLE 2
Gravity Pipe Construction Cost Factors

Type of Crossing	Cost Factor
Stream	3
Railroad	7

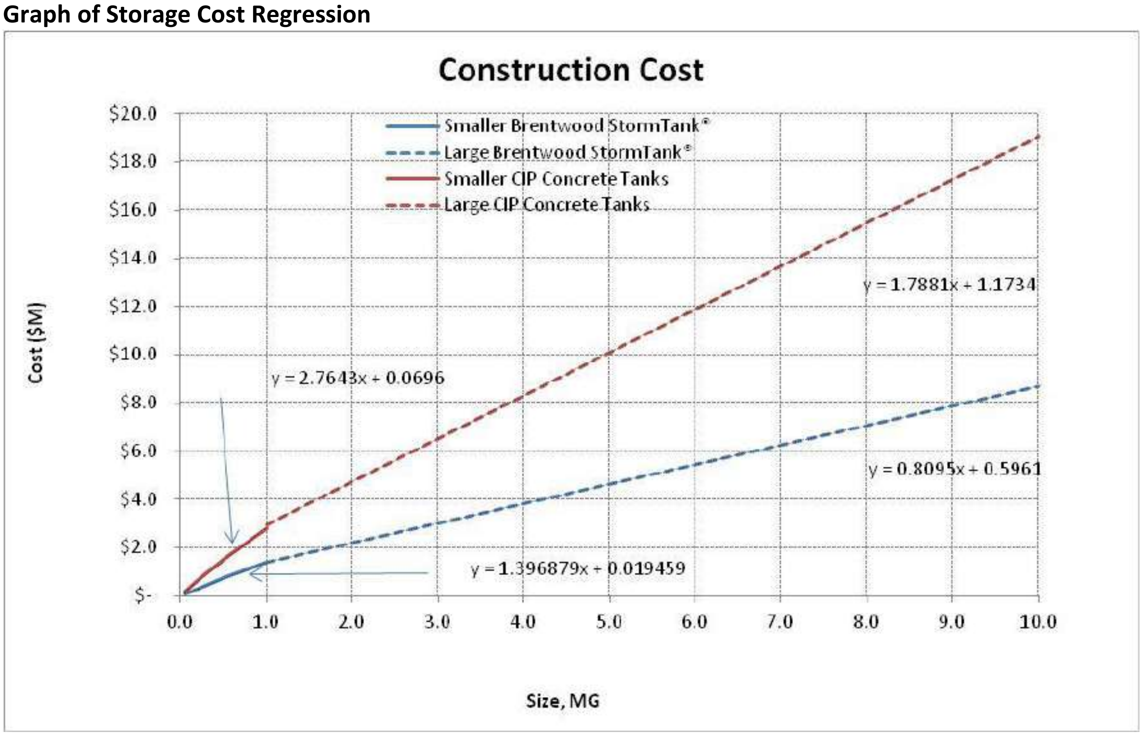
Storage Facility Cost Information

Cost estimates for the storage facilities were developed for two technologies: A traditional underground cast-in-place concrete tank and an alternative stackable modular unit installed underground and wrapped with an impermeable or permeable liner.

The CIP Concrete storage facility construction cost was developed as a customized cost estimate based on CH2M HILL's Program Alternative Cost Calculator (PACC) Tool. The costs are construction costs only and do not include administration costs, engineering costs, contingencies, and other soft costs. The costs for smaller storage units with volumes less than 1 million gallon were found to be high for the CIP concrete tank. Hence, a separate takeoff cost estimate was developed for smaller storage volume; less than 1 million gallons.

A separate cost estimate was developed for the stackable modular units. There is an increasing use of these technologies in the industry and the cost of installation is getting increasingly competitive compared to traditional storage methods. Construction costs were developed based on one such stackable modular unit, StormTank® modules by Brentwood Industries. The cost for the Brentwood StormTank® modules came out significantly less than that for CIP concrete tanks. For the purpose of the evaluation of watershed wide alternative solutions, the StormTank® modules was used as the most cost effective alternative, however site specific conditions will determine which technology will be most appropriate in a given location. For example a site with high water table may make the use of CIP concrete tanks preferable over the StormTank® modules. The estimated construction costs for the CIP concrete tanks and the Brentwood StormTank® are provided in Figure 1.

FIGURE 1
Graph of Storage Cost Regression



The following assumptions were made for storage tank selection and sizing:

1. Offline enclosed underground storage will be active only during wet weather events.
2. Options for odor control were not considered.
3. Costs for storage facilities with intermediate storage volumes were interpolated based on linear regression shown in Figure 1.

Green Infrastructure (GI) Cost Information

A variety of sources and professional judgment were used to develop the GI costs. Where technologies were directly comparable, costs were updated based on Fairfax County, VA unit cost schedule, March 2013. The unit costs used to develop GI implementation cost are included in Table 4. Costs reflecting stand-alone projects (e.g., installing a green roof on top of an existing building) were used for costing alternatives solutions. Incremental costs of adding GI to an existing project can provide significant savings and are provided for reference, but not used directly in cost estimates for this project.

In the CASSCA Project GI is being proposed as a series of GI programs applicable to specific land uses (e.g. green parking is applicable to parking lots). Each GI program may consist of multiple GI technologies which drive the cost of implementing that program. Table 5 lists and the relative amounts of area designated for the GI technologies assumed to be part of each GI program and the resultant unit cost for each GI program.

TABLE 4
Unit Construction Costs of Green Infrastructure Technologies

Green Technology	Stand Alone Cost Proposed for GI Plan ($/GI acre)	Loading Ratio (Ratio of Area Managed to Area of GI)	Stand-Alone Cost Proposed for GI Plan ($/acre managed)	Incremental GI Cost Compared to Stand-Alone
Native Landscaping/Soil Amend.	$ 5,000	1	$ 5,000	50%
Rain Barrels[1] and Native Landscaping/Soil Amend.	$ -	N/A	$ 15,000	90%
Cisterns[2]	N/A	N/A	$ 34,000	90%
Blue Street/Inlet control devices	N/A	N/A	$ 22,500	N/A
Rain Gardens	$ 436,000	12	$ 36,000	70%
Stormwater Trees[3]	$ 34,700	0.5	$ 69,000	50%
Bioswale/Bioretention	$ 1,045,000	12	$ 87,000	70%
Porous Pavement/ Infiltration Trench	$ 436,000	4	$ 109,000	70%
Green Roof[4]	$ 501,000	1	$ 501,000	43%

[1] Each rain barrel is assumed to manage 350 ft^2 of rooftop; therefore, 124.5 barrels are required for 1 acre of roof.
[2] Each 1000-gallon cistern is assumed to manage 6,500 ft^2 of impervious area; therefore, 6.7 barrels are required for 1 acre.
[3] Trees are assumed to have an average 10-foot canopy radius (314 ft^2), with 50 percent assumed to be overhanging impervious area.
[4] Incremental cost of green roofs set to 43 percent to match the District's $5/ ft^2 ($217,800/acre) green roof incentive program.

TABLE 5
Green Infrastructure Technology Elements and Unit Construction Cost of Each Green Program

Green Technology	% Area of Program Assigned to Each GI Technology						
	Blue Streets	Green Alley	Green Buildings	Green Parking	Green Roofs	Green Schools	Green Schools
Native Landscaping/Soil Amend.	-	-		-	-	-	-
Rain Barrels[1] and Native Landscaping/Soil Amend.	-	-	30%	-	-	-	-
Cisterns	-	-	10%	-	-	-	-
Blue Street/Inlet control devices	100%					-	-
Rain Gardens	-	-	30%	-	-	-	-
Stormwater Trees	-	-		-	-	-	30%
Bioswale/Bioretention	-	-	30%	50%	-	65%	30%
Porous Pavement/ Infiltration Trench	-	100%		50%	-	30%	40%
Green Roof	-	-	-	-	100%	5%	-
Unit Cost ($/acre managed)	**$22,500**	**$109,000**	**$44,800**	**$98,000**	**$501,000**	**$114,300**	**$90,400**

Three levels of green infrastructure implementation were evaluated for this project:

- High Implementation – Manage 50% of total impervious area in the shed
- Medium Implementation – Manage 30% of total impervious area in the shed
- Low Implementation – Manage 10% of total impervious area in the shed

The unit cost of implementing GI at the various implementation levels is driven by the availability of GI opportunity areas. As the area available to achieve a GI implementation level become scarce, the cost to achieve that level on GI implementation also increases. It was assumed that GI implementation would focus, in succession, from the most to the least cost effective programs and technologies. That is, for each level of GI implementation the most cost effective program and technologies would be implemented first until the available opportunities for those programs are exhausted. If the level of implementation is not achieved with the most cost effective program, the next most cost effective program is considered in that order until the desired level of GI implementation is achieved. Therefore Low Implementation would be more cost effective (lower cost per acre managed). The unit cost for each implementation level was computed separately for each watershed based on the cost information presented above and the distribution of areas available for GI implementation.

Green Opportunities

Opportunities for blue streets, green streets and alleys, green buildings, green parking, green roofs, and green schools were identified by completing a desktop analysis using the City's 2011 basemap data, including:

- Roads (Road_y and Road_lc)
- Buildings (Blds_y)
- Parking lots (Parking_y)
- Zoning (Zoning_y)
- Parcels (Parcels_y)

The approach to identifying potential opportunities for each program is provided below. All opportunities were combined into a single shapefile of polygons with an attribute for area calculated in acres.

Blue Streets

Local or Residential roads with an average slope less than or equal to 1% and a maximum slope less than or equal to 3%. Road slope was estimated using ArcGIS 3D Analyst tools and the Road_lc feature and City of Alexandria DEM as inputs.

Green Streets and Alleys

Green streets and alleys were identified using the Road_lc and Road_y features to identify roads classed as Arterial, Primary Collector, Residential Collector, Local, and Alley with an average slope less than or equal to 5%. Roadways that fall within school parcels were removed from this layer because they are included in the Green Schools program. Road slope was estimated using ArcGIS 3D analyst tools and the Road_lc feature and City of Alexandria DEM as inputs.

Green Buildings

Green buildings opportunities include buildings where disconnection may be possible. Based on a windshield survey of Taylor Run, approximately 50% of residential buildings, not including single family detached homes, may have opportunities for downspout disconnection. To identify these opportunities, buildings with a BUSE of '1-Residential' were selected from the Blds_y features to identify all residential buildings. This selection was narrowed to apartment buildings and larger residential developments, removing detached houses (BTYPE = 'Detached house'), buildings with less than 5 units (BUNITS < 5), as well as removing nursing homes, hotels, and detention centers. Residential buildings on school properties were also removed because those are accounted for in the Green Schools program. Buildings with a footprint greater than 20,000 square feet were also removed because these buildings are likely too large for a disconnection program.

The footprint of the final selection was reduced by approximately 50% (based on the result of the Taylor Run windshield survey) to approximate the total area of impervious surfaces that could potentially be managed through a disconnection program.

Green Parking

Green parking opportunities were identified as parking lots in the Parking_y feature class with a parking area over 3,000 square feet. Parking lots on school parcels were removed from this selection because they are accounted for in the Green Schools program.

Green Roofs

Green roof opportunities were identified by selecting buildings in the Blds_y feature class with a footprint over 20,000 ft^2 that have a building use (BUSE) of Commercial, Industrial, Institution, Transportation, and Multiple or Mixed use. Also included were buildings over 20,0000 ft^2 that were within a Commercial, Industrial, Coordinated Development District, or Mixed Use zone based on the Zoning_y feature class, unless those buildings were garage/sheds. Buildings on school parcels were removed from this selection because they are accounted for in the Green Schools program.

Green Schools

School parcels were identified by selecting all parcels with a land description (LANDDESC) of 'ED. PUBLIC SCHOOLS', 'PRIVATE ED ENSTS.', or 'ST. ED. INSTITUTIONS' or with an owner name or address that indicated it was school property. School buildings with potential for green roofs were identified by selecting all buildings on school parcels or buildings in the Blds_y features with the word 'school' in the building name (BNAME) or building campus (BCAMPUS) fields where the footprint is over 3,000 ft^2. All remaining impervious surfaces on the school parcels (roads, sidewalks, small buildings, recreation facilities, etc.) were identified as opportunities for green schools.